EVIDENCE BASED RESEARCH, INC.

A HUMAN-CENTRIC ARCHITECTURE FOR NET-CENTRIC OPERATIONS

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EXECUTIVE SUMMARY

Net-Centric Operations seek to improve military effectiveness among spatially distributed and possibly culturally diverse teams. Key to the net-centric operational concept are agile teams that excel even in the most difficult circumstances. Such teams can "self-synchronize," smoothly coordinating to exploit the diverse perspectives and expertise within the team. The members of such teams are on the same wavelength, continually making adjustments to leverage each others' abilities and to accommodate each others' needs.

Recent research on the cognitive foundations of collaboration and teamwork has identified key cognitive enablers to effective teamwork. These cognitive enablers are the knowledge and understandings that team members require to work together successfully. Accordingly, it is very desirable that teams acquire and maintain this knowledge. There are three technical prerequisites to ensure that spatially distributed team members can do this: an architecture that provides reliable communications connectivity among team members, information that supports task performance and team coordination, and a means for team members to evaluate performance and correct problems.

This report describes how to create an infrastructure that achieves these technical prerequisites (Figure 1). The key component is a set of "cognitive" node monitors that non-intrusively help team members know how they're doing. These monitors help team members review team workload, task progress, team concepts, and product quality. Directly supporting the cognitive node monitor are two classes of collaboration tools: 1) those that help feed the cognitive node monitors and 2) those that help the team address any problems the monitors might indicate. The architecture provides the connectivity and information management needed to support net-centric operations. This peer-to-peer agent based architecture facilitates information flow, helps integrate a collaboration tool suite tailored to team needs, and gathers and manages the cognitive node monitors.

The "cognitive" node monitors will enable team members to be more aware of what each other are doing, to be more aware of their task progress, to understand the concepts and issues that team members are attending to, to more easily identify areas of agreement and disagreement, and to assess the quality of team products and effects. It will automatically depict and quantify key cognitive issues that theory says are essential to effective teamwork.

Advanced technologies are needed to develop the peer-to-peer architecture and to create and update the cognitive node monitor. The peer-to-peer architecture will build on the EBR web-based war room architecture, developed using the Cocoon web-development framework, and the NPS collaboration architecture employing Groove peer-to-peer collaboration technology and the COABS agent management system. The generation and input of information in the cognitive monitoring nodes will use agent-based analyses of EWALL and DCODE records. Cognitive monitors will also be supported by watching user databases accesses, by analyzing team members' communications using Latent Semantic Analysis and other content analysis frameworks, and by tapping into an Earned Value Management tool used to integrate performance management with schedule and cost information.

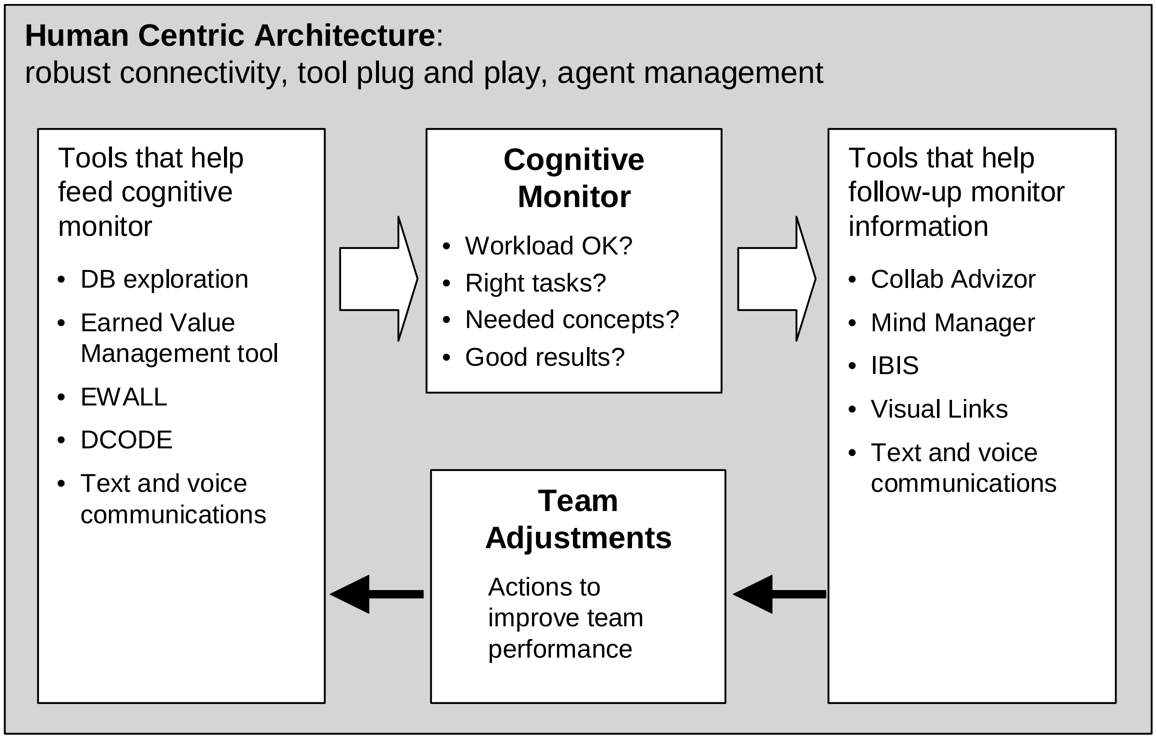

Figure 1. Infrastructure to Enable Effective Collaboration in Net-Centric Operations

The net-centric architecture will provide several collaboration tools that help teams follow-up on information from the cognitive monitors. The Collaboration Advizor, developed by EBR under a previous SBIR, will help teams explore and understand more fully issues that the cognitive monitors raise automatically. The Collaboration Advizor also helps team members identify key areas of agreement and disagreement among a broad spectrum of collaboration issues, and helps them identify how to fix problems. The Mind Manager and IBIS help teams structure and discuss problems. Visual Links helps them discover and understand key relationships within the team and in the external environment.

The cognitive-based architecture and the novel "cognitive" node monitors will benefit the Navy, DOD, and all others that aspire to excellent performance by their teams. It will improve team performance, helping team members stay on the same cognitive wavelength and helping them adjust and self-synchronous to maintain excellent performance throughout their mission. It will also help with performance evaluation, not only providing data that teams need to monitor their performance and correct weaknesses, but also providing critical team performance data necessary to evaluate new collaboration tools, organizations, and processes.

1. INTRODUCTION

1.1 Cognitive Fragmentation

This report describes a strategy and an architecture to help teams be more effective by avoiding "cognitive fragmentation." Cognitive fragmentation arises when team members do not understand how their work fits into the larger team fabric, do not know how perturbations to their work or others' tasks will ripple through the team, do not know how their understandings and viewpoints align with others', and do not know how the diverse backgrounds and expertise in the team can leverage and amplify each other to obtain a superior product that no single person on the team could have produced alone.

Cognitive fragmentation leads to many team problems. Cognitively fragmented teams cannot harmonize their intellects so that their many ideas can be combined to create an outstanding product, do not know how to determine the totality of viewpoints on the team, do not know where individual team members may have misgivings about team positions, do not know how to handle unexpected obstacles, and cannot gracefully adjust to new circumstances. In extreme cases, team members don't know where they are going, don't know what to do, don't talk to each other, don't know how to get information, and don't know who they should listen to.

Cognitive fragmentation can prevent a team from achieving superior results, despite ample resources and high motivation. Cognitive fragmentation can also cause serious team blunders. For example, it contributed to both of the two most serious, publicized, and analyzed team blunders, the Bay of Pigs invasion (Janis, 1972) and the Vincennes shoot down (Klein, 1998). In the Bay of Pigs case, where team members approved a highly flawed plan, team members did not share their individual reservations because they did not wish to undermine team harmony. Had team members been aware of each other's reservations, they might have discussed them more fully and avoided a calamitous decision. In the case of the Vincennes incident, no one had a full grasp of all of the team members' various incomplete and uncertain understandings concerning the different clues about the identity and behavior of the approaching airliner.

1.2 Understanding Cognitive Fragmentation

To find a way to help teams avoid cognitive fragmentation, we must first understand its cognitive causes, next know how to recognize it, and third know how to fix it. Figure 2 represents a teamwork process flow useful for understanding and addressing each of these issues.

The "teamwork and taskwork" block in Figure 2 is where the actual collaboration and work occur. It has two inputs: information and team members' knowledge. The latter is labeled "cognitive enablers." These enablers are the knowledge that team members need to work together effectively (Noble, 2004). Team members often use a variety of task, collaboration, and communications tools to help them carry out their work. Observers watching a team work can see the signs of their activity: they can see people busy doing work (workload), can see tasks being performed, can observe concepts being discussed or addressed, and can see the results in intermediate products. In the next block, "evaluation," team members assess the adequacy of their work, plan, and team performance. If everything is OK, then they continue their work. If they recognize problems and are a good team, then they try to fix the problems. Though the source of the problems may be poor resources or motivation, this process flow focuses on the problems that are cognitive because these are frequently the major (and sometimes unrecognized) drivers of team performance. After the team fixes their cognitive shortfalls, they continue their work.

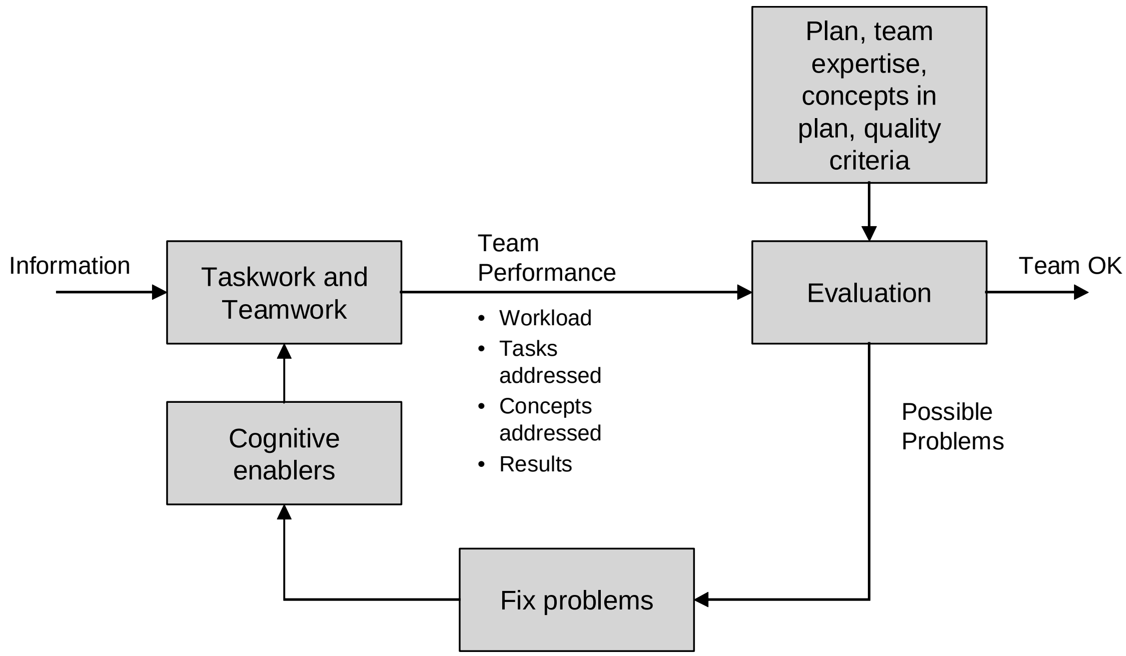

Figure 2. Evaluating Team Performance and Fixing Cognitive Collaboration

Cognitive enablers. In the framework of Figure 2, knowledge is central to successful teamwork and collaboration. The DTIC report "Understanding and Applying the Cognitive Foundations of Effective Teamwork" (Noble, 2004) grouped the knowledge that team members need to work together effectively into twelve knowledge enablers. Four of these (Table 1) are especially important for avoiding the problems of cognitive fragmentation.

1. Activity awareness, in which team members know what other team members are working on, know how busy others are, and know to what extent what others are working on is in accordance with the team's plans and team goals.

2. Task assessment, in which team members know what tasks are being performed, who is performing them, how they are progressing, what resources and information are needed to complete them successfully, what problems are being encountered, and what help should be offered.

3. Mutual understanding, where team members know what others know and know the extent to which other team members agree or disagree with each other and with the consensus of the team.

4. Situation understanding, in which team members know what is happening, know the underlying reasons for why this is happening, and can predict what could happen next should various future conditions prevail. They know, in addition, the evidence supporting their situation understanding, the signs that certain events are becoming more likely, and the situation uncertainties.

Table 1. Understandings Essential to Team Cognitive Unification

Activity Awareness	Task Assessment	Mutual Understanding	Situation Understanding
• What others are doing • How busy they are • Extent to which work accomplished adds to goal achievement	• Tasks being worked on, and by whom • Progress towards goal achievement • Possible problems and impact	• Others' expertise • Others current understandings • Extent others agree or disagree	• Surface understanding • Situation model • Evidence • Uncertainty

Taskwork, teamwork, and tools. Taskwork is the work that team members do to accomplish their individual tasks assignments. Teamwork is the work they do to maintain their team's health, to keep everyone on the same wavelength, and to contribute to team goals and objectives. Often, teams use some task and collaboration tools. Some of these focus on the specific needs of a particular task, such as a tool to help associate track reports with tracks or a tool to help structure free text. Others are more general, helping team members with many different kinds of tasks. Though there are numerous collaboration tools serving many different needs, there are three types of tools of special importance to addressing cognitive fragmentation: 1) the "cognitive monitors" that directly support several key cognitive enablers, help monitor critical aspects of team performance, and help teams determine if the team is experiencing problems that need attention; 2) tools that not only directly help with taskwork and teamwork, but also help feed the information that the cognitive monitors need; 3) tools that can help teams fix the problems the cognitive monitors detect. Figure 1 listed five tools in the second and third categories. Tools in the first category were the War Room database exploration tool, EWALL, DCODE, an Earned Value Management tool for measuring task progress, and text and text and voice communications. Tools in the second category include the Collaboration Advizor, Mind Manager, IBIS, and Visual Links, and communication tools.

Evaluation. To keep the team on track, team members need to monitor their performance and diagnose and fix problems. Skilled teams can do this if they know what to look for to recognize various team dysfunctions. Because the expertise to do this is often not available in a team, diagnosis tools can help the team recognize problems. One tool that helps teams do this is the Collaboration Advizor™, which EBR developed in a previous ONR research program. To use this expert system, team members answer a series of questions, which the tool then assembles to create a "team view" that summarizes critical team cognitive issues. This research will develop another tool to help with evaluation, the "cognitive monitors." Unlike the Collaboration Advizor, which requires team members to answer questions, the collaboration monitors will run automatically, tapping into team information generated as a by-product of the team's taskwork and teamwork tools.

Fix problems. Once the team understands the nature of their problems, they can address them. While the collaboration monitors will help team members be aware of general team issues, they do not drill down to the precise nature of the problem nor do they recommend how to fix these problems. In contrast, the Collaboration Advizor does both of these functions. The human-focused system includes the Collaboration Advizor as well as several other tools that help teams fix problems.

1.3 Report Overview

The goal of the "cognitive architecture for net-centric operations" is to help teams achieve superior results by 1) providing a set cognitive monitors that help prevent cognitive fragmentation by improving team transparency and helping team members detect team problems; 2) providing a set of tools that directly support teamwork and taskwork and also enhance the cognitive monitors; and 3) providing an architecture and physical infrastructure featuring robust connectivity, a powerful tool set, and intelligent information management.

Chapters 3, 4 and 5 discuss each of these issues in detail.

1. Chapter 3 discusses the cognitive monitors that help team members be aware of the status of critical aspects of the team, and help alert the team to possible team cognitive deficiencies. This chapter details what these monitors will do and outlines the technical approach for non-intrusively obtaining the monitoring data.

2. Chapter 4 describes a set of cognitively-focused tools that help team members do their jobs, and in addition help the cognitive monitors benefit the team. This report discusses two classes of such tools. The first are tools that can collect and feed information that the cognitive monitors need to make their assessments. The second are tools that can help teams further diagnose and then fix the problems cued by the monitors.

3. Chapter 5 describes our intelligent agent-based "human-focused architecture for net-centric operations." This architecture builds directly on the existing EBR war room and NPS architectures. It ensures connectivity among a distributed team,

collects and manages the information that the cognitive monitors need, and enables the integration of tools such as those described in Chapter 4.

In addition to the three chapters noted above, this report contains two additional sections. Chapter 2 describes the cognitive underpinnings to our approach. It describes cognitive fragmentation more fully, and explains why cognitive fragmentation is closely associated with the four cognitive enablers listed in Table 1.

Chapter 6 concludes this report by describing how this cognitive-focused architecture will significantly benefit the Navy and other organizations for which collaboration is important. It describes two kinds of benefits: 1) a technical infrastructure for superior team performance in challenging collaboration environments; and 2) instrumentation to support evaluation of team performance, as needed to evaluate new collaboration tools, processes, and organization.

2. COGNITIVE UNDERPINNINGS

This chapter reviews the theoretical justification for our design of the human-centered architecture. It first describes cognitive fragmentation in more detail, drawing on examples used in previous research (Noble, 2004). It then reviews a general framework for thinking about collaboration, making a case that knowledge is central to effective collaboration. Third, it suggests the particular knowledge shortfalls responsible for cognitive fragmentation, and argues that a system that can strengthen those knowledge areas will enable teams to avoid this problem.

Most of the material in this chapter was documented in the report "Understanding and Applying the Cognitive Foundations of Effective Teamwork" reporting work performed under previous research sponsored by the ONR's Human System's Department. In addition, it draws on work at the Naval Postgraduate School that independently documented the importance of team awareness to effective teamwork (Bordetsky, 2000).

2.1 Description of Cognitive Fragmentation

Cognitive fragmentation is individual team understandings that do not connect. It's people not knowing how their work fits with others, or not knowing that their activities conflict. It is having inconsistent understandings, and not knowing it.

In the initial research described in the DTIC report, EBR's subcontractor, Klein Associates, documented 20 cases of collaboration shortfalls. Unlike the well studied Bay of Pigs and Vincennes examples, all of these were everyday team problems. The two included in the DTIC report are also presented here, to illustrate cognitive fragmentation.

<u>*Example 1: Performing work no longer needed and too late to be useful*</u>

In a training exercise, a fire was reported in a room that contained an electrical box. By the time the engineering group was alerted, the simulated fire had already been extinguished with no harm to the electrical system. However, no one informed the engineers of this, and they spent the next hour and a half planning no longer needed contingencies should the electrical system be damaged. After they completed their plans and were about to present them to the entire Technical Support Center, they discovered that the fire was out. If the fire had been real, their planning would have come far too slowly to be useful. Yet they were congratulated on the quality of their plans.

This is cognitive fragmentation because part of the team did not know that their work was no longer necessary, and those that did know did not realize they needed to inform the others of this. In this case, the Klein Associates reviewers further noted that the team did not realize that anyone should have notified the engineers that the fire was out before they even began their deliberations.

Example 2: Taking the Wrong Action

In a small company, one individual had the job of keeping the computer systems working. One day a mouse stopped working that was attached to one of the main (critical) servers. The systems operator (sysop) sent a request to purchase a replacement. To make sure the request was perfectly clear, he tracked down when the original mouse had been ordered and wrote that he wanted the exact same mouse. He even included the date of the earlier purchase order for reference. He believed he had covered all bases. He had done a careful and thorough job. There should be no ambiguity.

To the sysop's surprise, the replacement mouse didn't work; it didn't even fit. Somehow the front office has ordered the wrong one. In tracking down the reason, the sysop found that the hardware company no longer made the original mouse.

The front office had assumed that the sysop was trying to indicate the company he preferred to order from. They contacted that company and ordered the mouse closest in price to the original. They were not aware that there was a compatibility problem, that not all mice fit all machines. To complicate matters further, the sysop was traveling when they ordered the mouse, so they could not ask him. Since they felt that he wanted the replacement quickly, they did not wait for him to return. They wanted to show how responsive they were.

This is cognitive fragmentation because the system operator's understanding was inconsistent with the front office's, and neither knew that it was.

2.2 The Importance of Knowledge to Effective Teamwork

The following four statements posit the key premises about the importance of knowledge for effective collaboration.

1. Knowledge is central to collaboration and teamwork. Teams whose members know what they need to know can work together effectively. Those that do not are prone to various kinds of predictable errors, with the type of error dependent on the type of knowledge deficiency. (Liang, 1995)

2. Knowledge must be distributed among members of a team. Everybody does not need to know everything for a team to be effective. But every team member does need to know how to get the knowledge he or she needs. (Wegner, 1987)

3. Individuals need to know about both "taskwork" and teamwork. Teamwork knowledge is what team members need to know to work together effectively . Taskwork knowledge is what team members need to know accomplish their part of the team's tasks. (Canon-Bowers, 1993)

4. The collaborative dialog helps generate the needed teamwork and taskwork knowledge. Team members exchange ideas to put in place the knowledge and understandings that team members must have for the team to achieve its mission. (Argote, 2000)

The first statement, that team members cannot work together effectively if they do not have the knowledge needed to do so, is our basic premise, and as written is almost a tautology. The second statement, that team members do not personally need to know all critical knowledge but do need to know who to ask to get the knowledge, is the basis of "transactive memory." Sharing the responsibility for keeping track of various kinds of information is one of the biggest advantages of teamwork. The third item emphasizes that all teams are really working on two basically different kinds of issues: (1) creating their task's products or performing task actions, and (2) maintaining team relationships. It is not enough for every team member to be an expert in their individual jobs for the team to succeed; team members also need to know how to work together. The last item addresses how team knowledge builds on itself. In teamwork, there is a kind of self reinforcing cycle. Knowledge is needed for teams to work together effectively, but teams need to work together in order to obtain this knowledge.

Figure 3 illustrates the relationship between knowledge (the "individual and shared understandings") and some key team activities: "team set up and adjustment," "group problem solving," and "synchronize and act." This diagram helps show how knowledge success begets success and small failures grow into big ones.

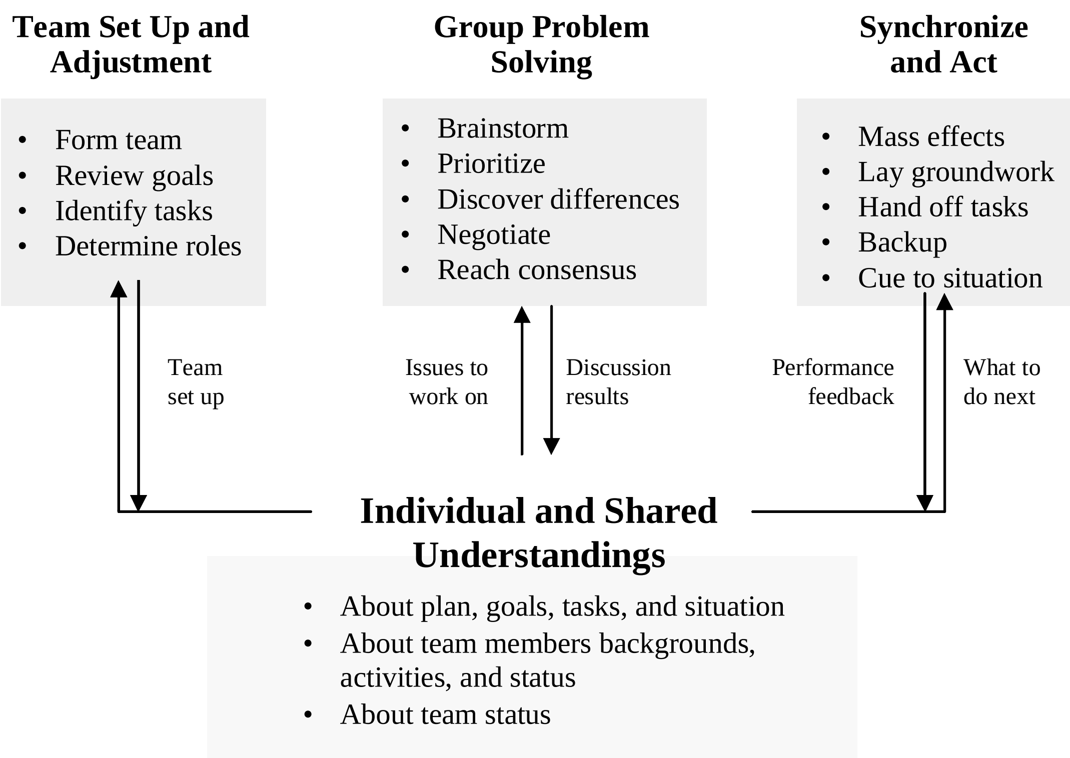

Figure 3. Relationship between Knowledge and Team Activities

All teams perform all three of these activities, generally moving from left to right but also switching back and forth among activities according to their immediate needs. In "set up and adjustment" the team organizes itself, reviewing goals, allocating roles and tasks, and defining the team's business rules. In the process of doing this, they generate and deposit critical team knowledge about goals, tasks, roles, and team interaction methods. Some of this knowledge may be written down in team documents, but much of it will reside as tacit knowledge in team members' minds. Team members need this knowledge when they carry out their "group problem solving." Here they identify and critique different issues, discover differences and align understandings, negotiate, and reach consensus about the nature of the problem and what they should do. When doing this, they draw on the knowledge acquired while performing earlier team tasks. As they progress, they refine and augment their knowledge with the results of their work. The same sequence also occurs with "synchronize and act." Team members draw on their knowledge to coordinate and help each other. They deposit knowledge about what works well and how they should interact as they work together.

This work-knowledge relationship can create highly damaging action-knowledge cycles. A small amount of missing knowledge can undermine a team activity that creates information critical to later team functions, and when missing, causes these later functions to fail. Thus, it is important for teams to catch these small knowledge gaps quickly, before they grow and cause significant damage.

2.3 The Four Cognitive Enablers Critical for Cognitive Fragmentation

Given that knowledge is critical to effective teamwork, the next step is to specify what the knowledge is. This knowledge is extensive, spanning both teamwork and taskwork, and incorporating both long term slowly changing knowledge as well as rapidly changing dynamic information. There are many different ways to organize this knowledge. The DTIC report divided the needed knowledge into the following twelve "knowledge enablers:"

Goal understanding. Knowing what the customer wants, and knowing the criteria for evaluating team products.

Understanding of roles, tasks, and schedule. Knowing who's supposed to do what and when, and with what information and resources.

Understanding of relationships and dependencies. Knowing how tasks affect each other and goals, and knowing how the external situation, information, and resources impact tasks.

Understanding others. Knowing other team members' backgrounds, capabilities, knowledge, work habits, and preferences are

Understanding of team "business rules." Having and knowing effective and agreed upon rules for team members to interact with each other.

Task skills. Knowing how to do one's assigned work, to include knowing how use task tools, find needed information, and get help.

Activity awareness. Knowing what others are doing now and the current need for doing it.

Understanding of the external situation. Knowing the status of people (including client), things, and events of the world outside of the team and projecting future changes.

Current task assessment. Keeping tasks on track, knowing how well own and other's tasks are progressing, and when to offer help.

Mutual understanding. Knowing what other team members understand now and knowing if they agree or disagree.

Plan assessment. Predicting whether the plan will still enable the team to achieve its goals.

Understanding of decision drivers. Judging and applying the criteria for selecting an action, and knowing the decision deadline, how to manage uncertainty, and involving the right people.

Four of these are of special significance to cognitive fragmentation. These are activity awareness, task assessment, mutual understanding, and situation understanding. Table 1 summarized the components of these enablers.

The elements of activity awareness, task assessment, and mutual understanding are straightforward to interpret. Because the elements of situation understanding reflect a cognitive theory of situation understanding, they warrant further explanation. As listed in Table 1, situation understanding has four components: surface understanding, situation model, evidence, and uncertainty.

- Surface understanding is knowledge of those aspects of the situation that lie on its surface. These aspects include the situation's entities, actors, physical environment, activities, and events.

- The situation model (sometimes called "deep understanding") describes how a situation works. It's the understandings that support inferences about unobserved parts of the situation and forecasts about the future. The situation model has three facets. First, it specifies the kind of situation at a level of abstraction suitable for inference based on generalization; e. g., this meeting is a kind of planning meeting. Second, it describes the typical and possible characteristics of that kind of situation, e.g., what usually happens at a planning meeting. Third, it describes the relationships between situation entities: what impacts what and how a change in one part of the situation causes change in another part.

- The evidence is the observables that led to the surface understanding and choice of situation model.

- The uncertainty includes uncertainties both about the surface understanding and situation model. There are three different kinds of uncertainty. The first is imprecision, in which the values of the elements in the situation are not known exactly. This is usually caused by insufficient information. The second is equivocality, "having multiple equally plausible interpretations of the same information" (Zack, 1999). In our framework, that is uncertainty about which situation model is appropriate. The third is ambiguity, when it is "not possible to make sense out situation, regardless of the available information" (Zack, 1999). This is an inability to find an appropriate situation model, leading to uncertainty about all the situation facets provided by the model.

2.4 Assertions

These assertions are the premises for the design of the human-focused architecture. They are:

1. If a team has adequate knowledge in the four fragmentation-related enablers, then the risk of cognitive fragmentation is much reduced.

2. If a team is having cognitive fragmentation, it's likely to show up as a reflection of these cognitive enablers

3. It is possible to create a set of autonomous monitors that can signal problems with these knowledge enablers, and that cue the team to address underlying problems in cognitive fragmentation.

The following chapter describes such a set of monitors. It describes what they do, what they might look like, how they work, and why we would expect them to address cognitive fragmentation.

3. COGNITIVE NODE MONITORS

The innovative cognitive node monitors are the centerpiece of our human-centric architecture. This chapter describes these cognitive node monitors and explains the technology through which they'll be created. It begins by specifying what information the monitors will provide, and illustrates possible computer output displays that depict this information. The chapter then explains how the monitor information products support the cognitive requirements described in the previous chapter. The next section explains the technical means through which data will be automatically collected as by-products of information that team members must generate to accomplish their tasks even were there no cognitive monitors. This section also explains the means through which the collected data can be transformed into the monitor outputs. Finally, the chapter describes a risk mitigation strategy to ensure that the government receives a high valued system even should some of the more ambitious goals not be fully realized.

Note that the node monitors are not monitors of the performance of individual team members, unless a team member is the only person at a node. More generally, they indicate the status of the component of a team at a particular node.

3.1 Cognitive Monitor Output

There are four cognitive node monitors, each displaying information about a different aspect of the work being performed by each "node" of the team. Here a node is one or more people working on the same task at the same place. The four different node monitors address: 1) the extent to which team members are coping with their work; 2) task progress; 3) concepts and issues being addressed; and 4) the quality of intermediate products. For the second, third and fourth items, the monitor will produce both basic status information (what is happening) and evaluation information (how well it's proceeding and how good its quality is). Table 2 summarizes the information contained in each of these four areas.

Table 2. Cognitive Node Monitor Information Products

Monitor Type	Status Information	Evaluative Information
Coping	NA	Extent that team component is handling workload and stress, and keeping up with tasks
Task Assessment	Measured progress on assigned tasks.	Task progress with respect to schedule, cost, & value Tasks that are scheduled, but are not being addressed
Concept Flow	Concepts and issues being addressed at each node Concepts and issues being received or output by each node	Extent that the team component is addressing the concepts and issues specified by the "issues" plan
Intermediate Products	Products being produced at each node	Quality of these intermediate products

Coping monitor. This monitor measures how busy the people at a node are, mostly by assessing how well the team members at that node are keeping up with their tasks. The coping monitor addresses the first element of the "activity awareness" enabler, how busy team members are.

Table 3 summarizes the three levels of coping which the coping monitor will infer. It also summarizes some of the behaviors associated with each level of coping.

Table 3. Levels of Coping Reported by the Coping Monitor.

Level	Description	Associated Behaviors
Normal	No anticipated difficulty achieving goals with the allocated resources. Time is available to help others as anticipated in baseline plan	Performing some work not directly related to tasks Meeting measured milestones and deliveries No indications of task or goal conflict.
High	Expect to achieve all goals with allocated resources. However, there is little or no time to address additional tasks	More time at workstation; Ability to perform scheduled tasks Very little, if any, work on tasks not related to immediate goals Comments about "I'm too busy to do this," or "don't bother me now"
Overload	Does not expect to achieve tasked goals. Additional expertise, time or resources will be required.	More time at workstation. Working additional hours. Not achieving performance measures. Requests for additional resources or additional expertise. Failure to perform some scheduled tasks

Task Assessment. The task assessment monitor shows the tasks that are being worked on, where the people at a node are in a task, and what value is being delivered to the task. The assessment tool can provide expected completion time and expected completion cost in labor compared to the time and cost projection in the baseline. It also indicates tasks that are scheduled but are not being worked on.

The following example illustrates what the task monitor monitors. Suppose that a team is making a plan to help the victims of a major natural disaster, such as the recent Tsunami. The team's task is to make a plan. To create a plan, the planners need to perform the following activities:

Clarify and state plan objectives, perhaps by defining the desired plan end state

1. Determine alternative high level courses of action

2. Select a course of action

3. Determine tasks

4. Assign resources (personnel and material) to the task
5. Create a task schedule
6. Determine conditions that may arise which would prevent the plan from working, and develop contingencies for these conditions
7. Identify measures to determine the value of the work performed to goal satisfaction.

The task monitor will measure and report task progress. It will also report the schedule completion time and cost for the task, if the planners developed a detailed schedule and resource requirements projection.

Concept flow. Concepts refer to the issues or factors that are being worked on at a node. They are the factors that need to be addressed when performing a task. In the case of planning relief after a natural disaster, the planning team would need to consider the following issues:

1. The needs of the people at a particular location. These are for food, shelter, and medicine.
2. The priority of addressing these needs. Some are life-threatening and must be addressed immediately. There are others that delays do not matter.
3. The location of resources for addressing these needs
4. Means for transporting resources to locations where needed
5. Means to coordinate this relief effort with what others are doing

Note the distinction between what the task assessment monitor measures and what the concept monitor tracks. The former monitors progress through the various steps of a task. In contrast, the latter tracks the concepts or issues that need to be addressed in carrying out the task.

The status information for the concept monitor notes what concepts are being addressed at a node. The evaluative information compares these concepts with the concepts which the plan specifies need to be addressed in completing the task.

Because the concept monitor software can determine the concepts being imported and exported from a node, it can create a map of the flows of concepts within the team. Thus, the concept map becomes a counterpart to the traffic flow analysis of the physical monitor. However, rather than measuring bit stream volume, the concept flow monitor measures the concepts flowing into and out of a node. This concept map can then show:

1. Input to a node, from other team members or from outside of the team.

2. Input to a node from information repositories

3. Output from node to information repositories.

4. Output from node to other team members of to locations outside of the team

In its evaluative mode, the concept map can compare the concepts being worked on at a node with the concepts the plan specifies as important to work on. The concept mode can also note the extent to which team members draw on the expertise within the team. If the team prepares a "transactive memory" map that specifies who is responsible for various types of knowledge and who has experience and expertise in various fields, then the concept flow map can show the extent to which team members draw on team expertise.

As will be discussed in Section 3.4, we anticipate that the concepts to be identified and displayed by the concept monitor will be defined by a formal ontology, and recognize using Latent Semantic Analysis and/ or other content analysis tools.

Intermediate products. As team members do their work, they create products or create impacts on the environment. If the products are deposited in the database, then they may be inspected for content, and summarized using the same techniques as used for the concept node monitor. If the "products" are the team's impact on the environment, (e.g., number of satisfied customers in a customer service organization), then the "product" must be extracted from records about the state of the environment.

As in the task assessment and concept flow monitors, the intermediate product monitors can have an evaluative output, provided that the plan specifies the criteria for a good product. These criteria can specify the concepts that a product should address. The evaluative output can then note the number of these concepts that are addressed. It is also possible that techniques that Latent Semantic Analysis uses to evaluate essay question answers can help the intermediate product monitor to quantify the quality of the concepts in the intermediate products.

3.2 Node Monitor Visualizations

The node cognitive monitors summarize team performance in four areas: coping (extent team members are keeping up with required work); task progress, concept flow, and quality of intermediate products. The monitor outputs can alert the team to problems in any of these four areas. In addition, they can increase team transparency by helping team members see how each node is doing in each of these four areas.

The node monitors will reside continuously in a small window on the computer screen, much as the physical node monitors do today in the NPS architecture (shown in Figure 17 in Chapter 5). Figure 4 illustrates the cognitive monitor depiction that may be permanently resident in the upper-left corner of the screen.

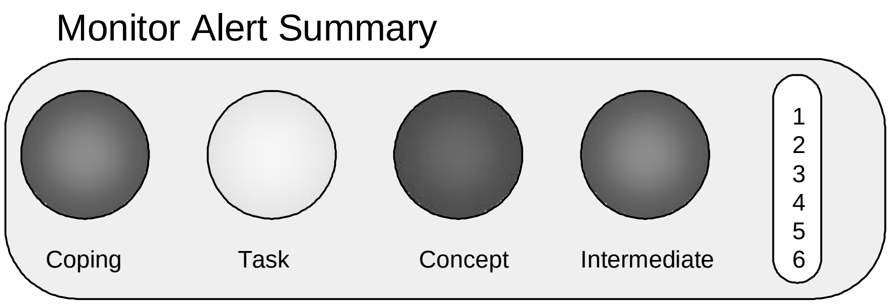

Figure 4. Cognitive Node Summary in Permanent Display

This display aggregates performance data for the team as a whole. In this display, a stop light shows the team status for each of the four monitoring areas. The stop light is green if all nodes are performing well in that area. It's yellow if at least one node is experiencing some difficulty. It's red if one or more nodes are performing poorly.

By clicking on a monitor stop light, the monitor shows the status of that monitor at each of the nodes, as shown in Figure 5.

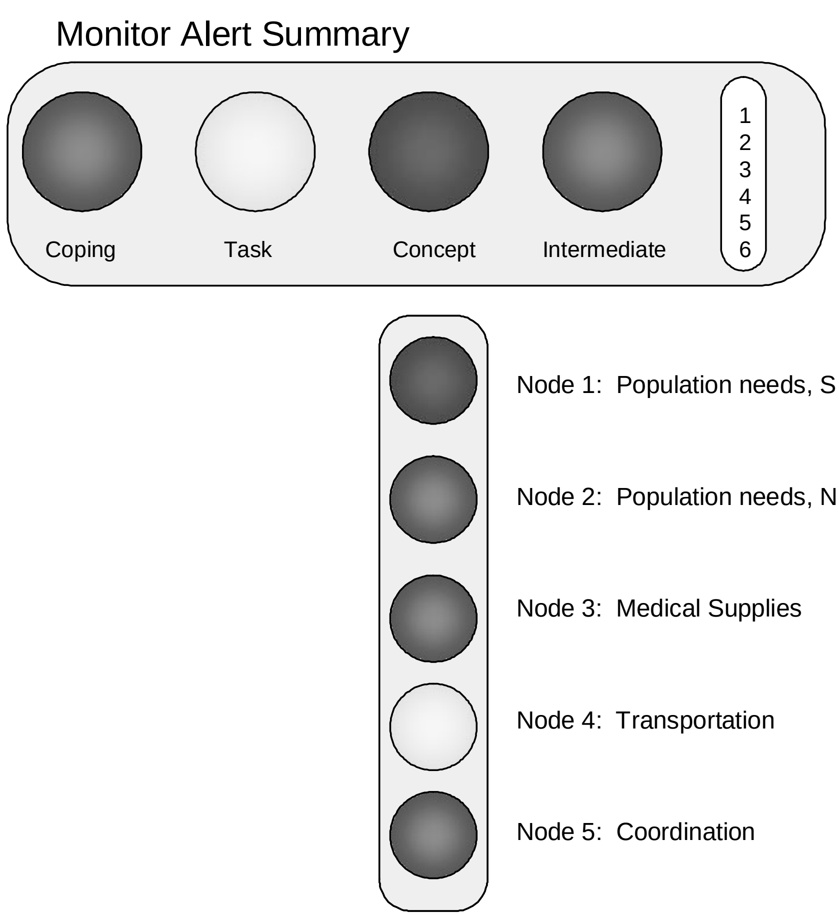

Figure 5. Concept Flow Performance for Each of the Team Nodes

This example is for a team planning disaster relief. For purposes of illustration, we assume it has five nodes: for determining relief needs in the southern part of the disaster area and for the northern part, for finding the sources for needed medical supplies, for arranging transportation, and for coordinating with other relief areas. Here, node 1, the people determining the needs of the population in the southern part of the disaster area, is having significant problems addressing the concepts that the plan says the people at the node should be addressing. Node 4 is having some difficulties. These difficulties may be failure to address concepts, or failure to communicate the concept to the appropriate people, or failure to draw on available team expertise.

If a team member wishes to view how the people at a node are doing in each of the four monitoring areas, he may click on the vertical bar to the right of the permanent monitor. In that case, a display such as Figure 6 would appear. The node selected is noted over the figure. It's also noted in the vertical box at the right of the figure. Team members can directly view another node by clicking within this vertical box.

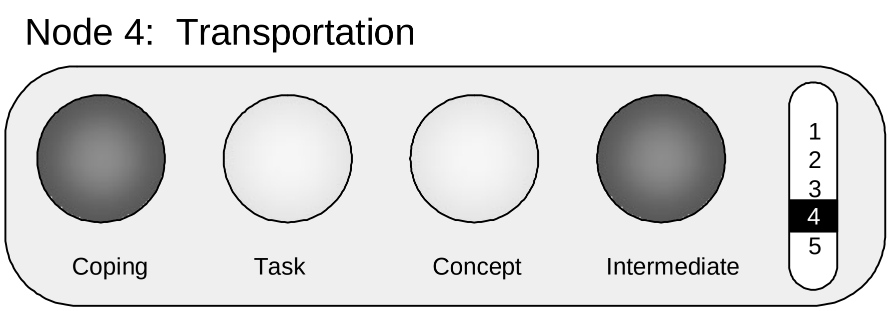

Figure 6. Performance at a Node in Each of the Monitor Areas

If a team member wishes to review the concepts being addressed at a node, he may click on the concept stop light in Figure 6 to bring up the concept map shown in Figure 7.

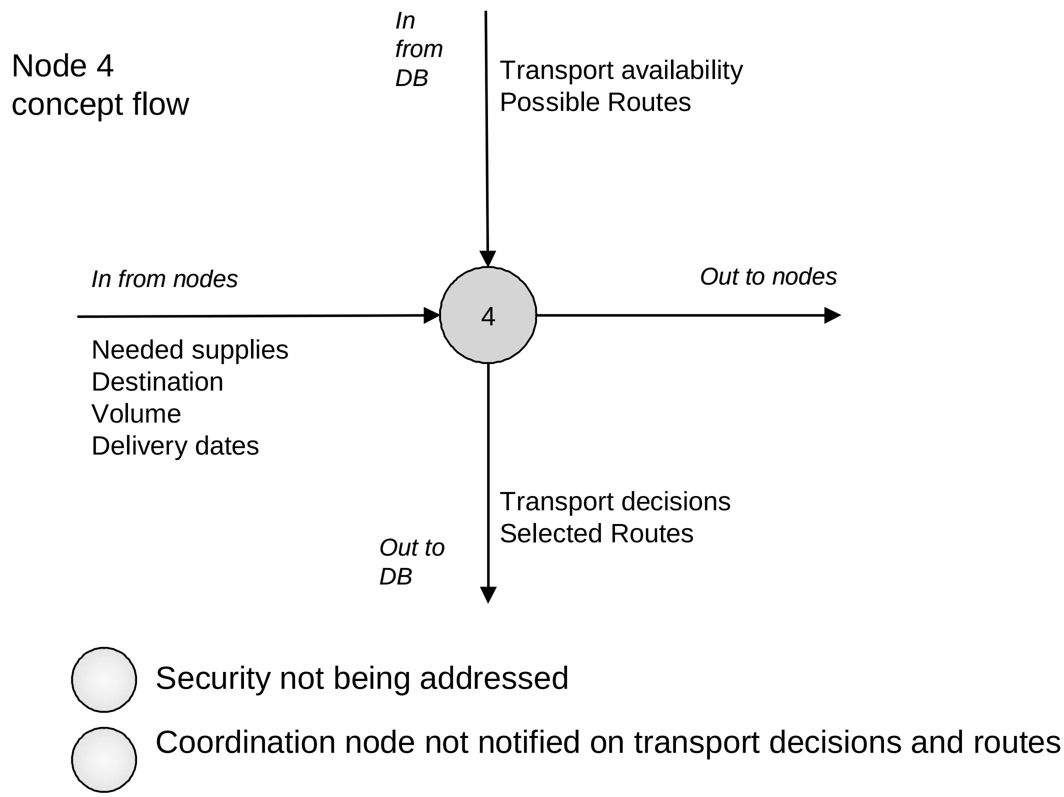

Figure 7. Concept Flow at Node 4, Transportation Node

As shown in this figure, other nodes have sent information to node 4 that address concepts concerning needed supplies (users would see specific sources of information by clicking on the "input" arrow), needed destinations for these supplies, volume of supplies needed, and needed delivery dates. Node 4 has extracted from the database information about transport availability and possible routes, and has deposited in the database information about transport and route decisions. This node has not sent this information to other nodes.

The monitor assigns a yellow stop light to this node because these concept flows differ from the plan concept flow in two different ways. First, the node so far has not addressed security for the transport of supplies to the disaster areas. Second, the node has not communicated with the people responsible for coordinating with other relief teams.

3.3 Requirements Satisfaction

The cognitive monitors help team members achieve a common understanding of team and task issues in two different ways. First, by improving team transparency, they directly support the four cognitive enablers (described in Chapter 2) that help teams avoid cognitive fragmentation. Second, they can cue team problems that may stem from cognitive fragmentation, which can then prompt teams to take corrective actions.

Support to cognitive enablers. Table 4 summarizes how each of the four cognitive monitors supports the activity awareness, task assessment, mutual understanding, and situation understanding cognitive enablers. This table distinguishes between support from the status indicators or from the evaluative indicators. It also notes indirect support, where a team member can infer some aspect of the cognitive enabler from the monitor information.

Table 4. How Cognitive Monitor Output Support the Four Fragmentation-Focused Enablers

	Coping Meter	**Task Assessment**	**Concept Flow Map**	**Intermediate Products**
Activity Awareness				
What others are doing		Tasks	Concepts[1]	Implied by products
How busy they are				
Extent in accordance with plan and goals				
Task Assessment				
Tasks being worked on, and by whom				
Progress				
Possible problems and impact	Implied by overly busy	Implied by poor progress	Implied by not addressing needed issues	Implied by poor quality products
Resource needs				
Mutual Understanding				
Others' expertise			Shown by expertise map	Implied by products
Others current understandings			From concepts	
Extent others agree or disagree			Inferable by comparing concepts	
Situation Understanding				
Surface understanding			At concept level	Inferred from product content
Situation model			At concept level	
Evidence				
Uncertainty			At concept level	

Legend:

Support from status indicators

Support from evaluative indicators

Note that the concept monitor can track only those concepts or issues that the monitors have been set up to recognize, and generally only at an abstract level. Thus, if set up to do so, they can recognize when team members are addressing various aspects of a situation. We do not anticipate that they will be set to recognize detailed issues, such as whether team members have identified the precise needs of people at a particular location in the disaster relief example.

Cue team problems that may stem from cognitive fragmentation. Some readings of the cognitive monitor outputs, such as team work overload, failure to discuss needed concepts, and falling behind in one's tasks, are indicators of team problems. Most of these cognitive outputs can have multiple causes, some of which are not related to cognitive fragmentation and some of which are. Table 5 shows some of the fragmentation behaviors that might be inferred from monitor output.

Table 5. How Cognitive Monitor Output Cues to Cognitive Fragmentation

Monitor Outputs Symptomatic of Fragmentation-Related Problems	Fragmentation-Related Behaviors Monitors Output Might be Reflecting
Coping Meter	
Team unable to keep up with workload	Not receiving needed help/expertise from others
Task Assessment	
Some scheduled tasks neglected	Failure to work on tasks others depend on Failure of others to cue responsible component to work on task
Schedule slippage	Node not receiving needed help/expertise from others
Concept Flow	
Called for concepts and issues neglected	No one working on an issue Experts not involved in working an issue Others on team don't cue node to address concept
Concepts needed by a node not receiving concepts developed elsewhere	No flow between people performing tasks and experts who can help
Intermediate Products	
Some needed products not being produced at each node	Lack of needed input from others or lack of awareness of what others need
Some intermediate products are low quality	Lack of needed input from others or lack of awareness of what others need

3.4 Technologies to Generate Monitor Output

The non-intrusive means to collect the performance data that the monitors need and to automatically generate the monitor output are important science and technology contributions of this STTR. The generation of monitor outputs requires two capabilities:

1. The ability to collect the required the data in an unobtrusive manner that does not increase the workload of the team
2. The ability to correctly analyze the data to measure coping level, task progress, concepts addressed and intermediate products at each team node

Table 6 summarizes for each of the monitors required data, sources for these data, and analysis processes. In addition to the required data elements in Table 6, the monitor generation processes will draw on communications among team members to help estimate team performance at a node.

As will be described more completely in Chapter 4, four specific tools, in addition to the variety of communication means, will contribute data to the monitor analysis processes. These tools are the war room's data base exploration tool, DCODE, EWALL, and EVMS.

Table 6. Information and Processing Requirements for the Node Monitor

Cognitive Monitor Element	Required data elements	Where the data will come from	Analysis Processes
Task Assessment	Baseline budget and schedule Work Performed Costs expended Milestones Achieved Performance Metrics	Earned Value Management System (EVMS) Project Management System Deliverables	Variance, Cost Performance Index (CPI), Schedule Performance Index(SPI),
Coping Monitor	Scheduled Workload Work Performed Staff Allocation Milestones Achieved Performance Metrics	EVMS Project Management System Deliverables	SPI Latent Semantic Analysis (LSA) Information Extraction
Concept Flow	Concepts associated with scheduled tasks Concepts contained in communications and work products	Planning documents and associated reference material Captured and stored communications and deliverables DCODE and EWALL Database transactions	LSA Information Extraction,
Intermediate Products	Intermediate Deliverables Performance and quality metrics	Deliverables Planning Documents Database	LSA Information Extraction

The analytical processes are the means by which the collected data are converted into monitor output. There are two basic kinds of analysis that will be used. The task assessment analyses are part of basic, industry accepted methods of task performance analysis included in Earned Value Management Systems (EVMS). These include determination of actual task progress as compared to resource expenditures and the variances and indices that are essential to this analysis. More detailed descriptions of the ones we will employ are included in the Task Assessment portion of the monitor.

The second kinds of analyses necessary are methods that automatically analyze text to find specific events or analyze the information within the team communications and task products. Two kinds of analyses are important for the node monitor: Latent Semantic Analysis (LSA) and Information Extraction (IE).

LSA is an automatic method of analyzing the semantic information within the text of the communications and work products and comparing that information to specific domains (Landauer, Foltz and Lanham, 1998). The process involves "training" the system using domain specific documents and text and then correlating documents to be analyzed against that domain. This research into the use of this analytical method has shown that it can be useful in determining the content of team communications. (Gorman, Foltz, Kiekel, Martin, Cooke) The advantage to using this method is that the training set and the input set do not have to use the same key words or phrases to generate a high correlation. The disadvantage is that the training set has to be assembled and analyzed by the system before the input documents can be compared and correlated. The scope of the training set determines what the input documents will be compared to.

Information Extraction is another method of analyzing unstructured text to find specific events and related entities. Rules for finding the patterns of entities (people, places, time, things, etc.) are developed. These include grammatical, ontological, orthographic, semantic and specific lists for finding these entities. Entities are then assembled into patterns to include specific event verb groups so that these events can be detected in the text. The advantage to this method is that it requires no corpus of training documents for comparison. The disadvantage is that the rules and patterns are specific and each possible variation of the event must be described in detail. EBR war room makes extensive use of information extraction to find events and entities and we have significant experience in incorporating these systems into text analysis applications.

Each of the four node monitors uses a combination of some of these analytical methods. The following describes how the parts of the monitor assess the input data to create the assessment of team health.

3.4.1 Task Assessment

The key to evaluating task progress is to analyze the actual performance of the team in carrying out the taskwork. The proper performance and management of projects requires specific reporting that teams need in order to measure and report on progress. Both the task assessment monitor and coping monitor can take advantage of this reporting.

The specific reporting required for performance management includes:

1. Work performed by task – how much time did team members spend working on a particular task

2. Work scheduled by task – how much work was supposed to be performed by this time on this task according to the plan

3. The cost of the work performed

4. The value of the work performed – what deliverables or milestones were achieved and how much were those worth toward the overall completion of the task

These data elements can be used in the Earned Value Management System (EVMS) to calculate the overall performance of the team on the tasks and perform some variance analysis. These performance metrics for the current work performed include cost variance, schedule variance, and cost performance index:

Cost Variance (CV) = Budgeted Cost of Work Performed (BCWP) – Actual Cost of Work Performed (ACWP)

Schedule Variance (SV) = Budgeted Cost of Work Performed (BCWP) – Budgeted Cost of Work Planned to be performed at that point in time

These variances show how well the team is keeping to the schedule according to the achievement of performance milestones and the time and cost of achieving these milestones. Additionally, these same data elements can be used to calculate the cost performance index using the formula:

Cost Performance Index (CPI) = BCWP / ACWP

This CPI is a useful measurement to determine overall performance of the team. For example, a CPI of 0.75 indicates that for every dollar the team is spending, they are only getting 75 cents of value toward completion of the tasks.

The use of variance and CPI will use overall performance on the tasks as an indication of team performance as a whole. Generally, teams that work well together will keep to the planned budget and schedule. Figure 8 below shows the decision process that will alert the team to potential problems.

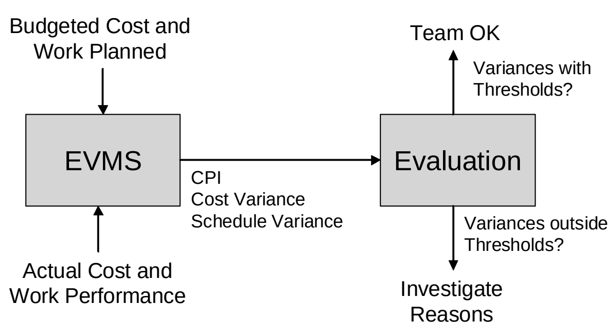

Figure 8. Task Assessment Process

The variance analysis is important to discover if the team is getting too far ahead or behind in any one task in the project. Getting too far ahead might signal team burnout or too much effort to one part of the project. Getting too far behind indicates a host of other possible problems that need to be investigated as well.

3.4.2 Coping Monitor

The coping monitor is closely related to the task assessment monitor described above. When the team is not keeping up with the tasks, one reason might be that the members of the team are just too busy to do all the work they need to do. The coping monitor will alert the team when there are indications of work overload so that further investigation can be performed to determine the underlying reason for the problem.

The team assessment monitor collected data from the project management and earned value management systems to assess the task performance. The coping monitor can use the same data, but needs to consider only the workload aspects of the team. In this way, it can isolate the indications of work overload from other problems such as resource constraints or external factors.

The coping monitor will also benefit by capturing and analyzing the communications among the team members to search for indications of work overload. Communications can contribute to measurement of team member workload by capturing such comments as “I’m too busy to talk to you now.”

Determining the workload aspects of task assessment is a relatively simple process. Since team members will be reporting their actual work progress, the coping monitor can use the schedule variance described above to assess workload progress on each of the tasks. This variance can be then correlated to the team members performing each task to see if particular nodes correlate to schedule problems. If tasks associated with a particular node are routinely running a negative schedule variance, this becomes an indicator that there is a possible overload situation at that node.

The other indicator of overload contained in the communication will need to be assessed with automated analysis of the text. This will require several steps to achieve.

1. The first step is to capture the communication in structured records. These records will need to include the sender, the receiver, the time and the content of the communication. Capturing text based communications such as e-mail will include all these elements and since e-mail travels through servers, it is possible to perform analysis on the entire corpus of e-mail communications. Voice communications can be captured using transcription technologies to convert the voice to text.

2. The second step involves setting up the system to recognize the indications of work overload and set the thresholds for when this indicates a problem that needs to be addressed. The thresholds might include the overall density of overload statements, the concentration of these statements to particular nodes or the degree of severity of the statements. LSA, keyword and concept searching and rule based event extraction are all viable methods of recognizing the indications of work overload. Research performed by New Mexico State University in the use of LSA in measuring the content of team communications supports the efforts in this part of the cognitive node monitor. (Nancy Cooke and NMSU). The key to success will be ensuring that a sufficiently large corpus of documents can be assembled to properly “train” the LSA system, or that concepts and

events related to work overload problems can be identified so that other analysis tools can be used.

3. Once the data is captured and the analysis system is setup, the next step will be to perform the comparison of the captured communications with the indications of work overload that have been set up in the system. These indications will generate an alert that can be compared to a set of metrics to drive the coping monitor and alert the team to a potential problem.

The output alerts from the communications content analysis, when combined with the workload and schedule variance data from the task assessment, provides the complete data requirements for the coping monitor. Figure 9 shows the flow chart of how these work together to create this monitor.

The analyses of how well the individual node is performing on its tasks and how they are keeping up will alert the team to potential problems. It will usually be necessary to follow-up investigation to determine the cause. Chapter 4 describes tools that can help the team diagnose and fix the problem.

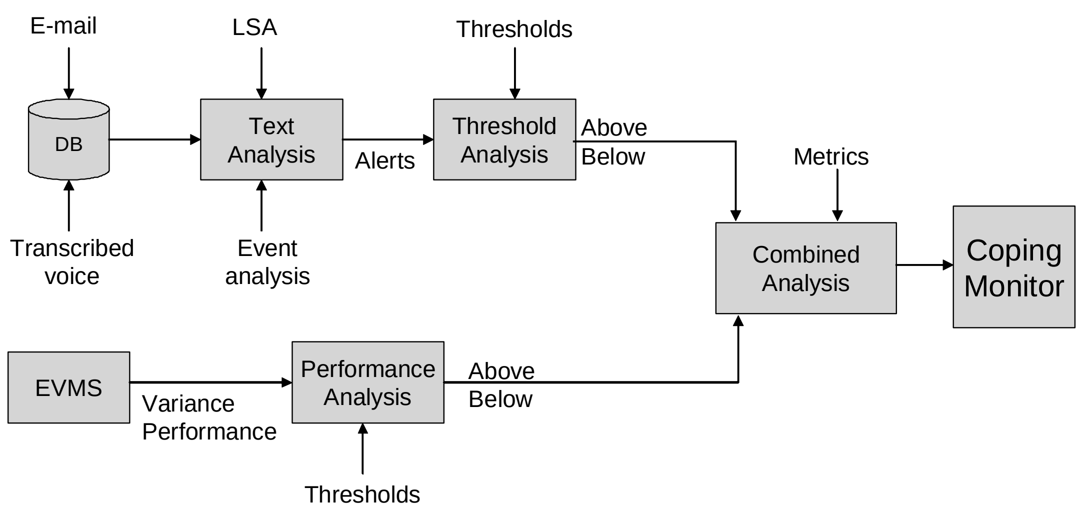

Figure 9. Coping Monitor Process

3.4.3 Concept Flow

The concept flow monitor identifies the concepts that are being addressed at a node or communicated among the nodes, and compares these concepts to those that should be discussed based on the project plan and distribution of expertise in the team.

The three major aspects of the concept flow monitor are 1) the determination of the concepts that should be discussed as specified by the plan, 2) the assessment of the information being analyzed by the various experts on the team, and 3) the assessment of the content of the communications among the team and the experts as compared to the plan. In contrast to the physical node monitor that analyzes the amount of traffic between nodes, the concept flow monitor will analyze the content of that communication to determine the flow of concepts among nodes and the extent to which this flow is in accordance with what the plan expects.

The first step to generating the concept flow monitor's output is to determine the concepts that the plan expects should be discussed at various times. When a team plans properly for a task, it develops various planning documents that define the scope of work, the tasking for each member of the team, the schedule for that tasking, the goals and objectives and many other things that determine what should be talked about and when it should be talked about. It is these documents, as well as the reference materials that have been used to develop them, that will serve as the baseline of the concept flow plan.

The LSA process will then take these documents and create a domain specific semantic map that changes over time. This map determines what concepts should be discussed, by whom, and when. It will also serve as the baseline for determining if the team is receiving the correct external data at the right time.

Once this domain specific concept map is completed, it can be used as the baseline to compare the input documents and the content of communications. The concept map can be used to create a database of specific tags to be compared with the input data so that the input data can be categorized and evaluated. The concept flow monitor will make two kinds of comparisons. It will compare the concepts in the communications in and out of the node with the concepts specified by the plan. It will also assess whether the node is receiving the correct information from the various information repositories.

The physical architecture will capture the communications in and out of any node and from the information repositories. This will create another repository of information that will be used in the LSA process to determine whether the content is in accordance with the plan. Tools such as DCODE and EWALL will also serve to collect and store the information. DCODE will be used by experts to collect and categorize the information received from outside the team so that the correct part of the team can use it. EWALL can be used to collect and store the current work products and ideas that are being discussed by each member of the team. A map will then be created and the comparison to the plan map can be made. If the comparison does not correlate within the determined thresholds, then the team can be alerted. Figure 10 shows the flow chart of how these will work together to create this part of the node monitor.

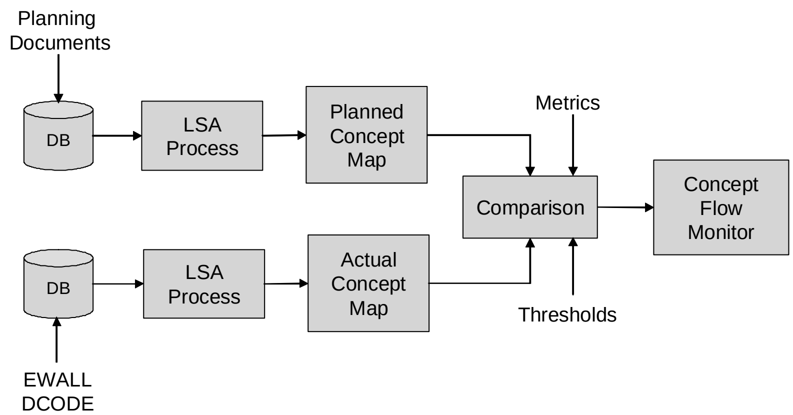

Figure 10. Concept Flow Monitor Process

This concept flow monitor is a critical piece in the cognitive assessment of the team's health. It will ensure that the team is both communicating and discussing the right things at the right time. It will also indicate the level to which the team is taking advantage of the experts on the team. Since the experts will be the ones receiving the data and categorizing it with DCODE for input to the LSA process, the concept flow monitor will then indicate whether or not they are participating in any further discussions about those concepts.

3.4.4 Interim Products

This part of the monitor leverages the concept flow monitor and adds another assessment, the determination of the overall quality of the interim work products. There are two basic steps to making this part of the monitor work. Metrics of product quality have to be determined and comparisons of the work products against those metrics have to be made.

Determining product quality depends on the nature of the interim products. They might include measures such as the extent to all the correct concepts are in the document, the level of completion to which they're discussed, and are the extent to which the correct members of the team participating in the creation of that product.

The LSA process is capable of determining the quality of work products. Tools that employ LSA are already being used to do automatic grading of essay questions in standardized tests. That capability can be leveraged to determine the overall quality of interim work products.

There are three main steps in determining the overall quality of the interim work products. The first will be to collect or create the necessary reference documents to train the LSA system for an assessment of quality and completeness. These documents will be drawn from planning documents that describe the tasks and their overall goals and objectives. The training of the LSA system can include both analysis and determination of the overall domain for a complete document, and also a tagging process that will identify the main concepts and compare the work products to the set of tagged documents to ensure that all the various concepts are included (Gorman, Foltz, Kiekel, Martin, Cooke).

Once the training of the system is complete, the next step is to capture the interim products for analysis. The interim products that will be used for this analysis can be stored in EWALL as well as the product database.

Finally, an analysis of the work products comparing them to the reference documents using the LSA system will show the correlation to the semantic space defined in the reference documents, as well as a mapping to the tag database for key concepts. Figure 11 is a flow chart showing this process.

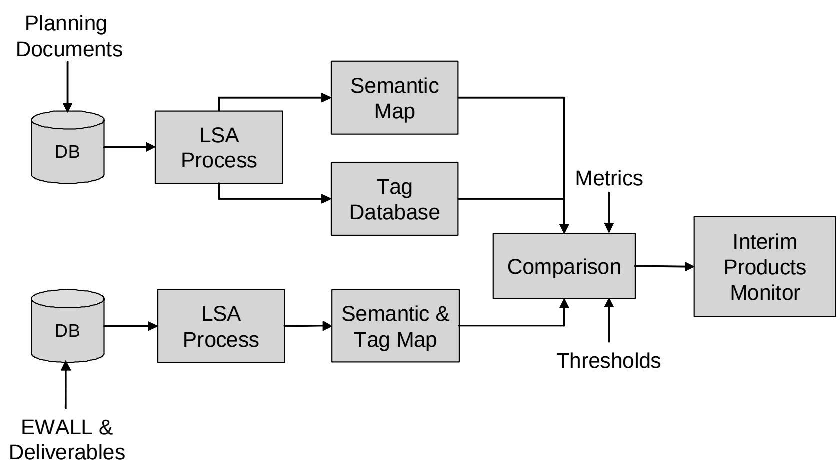

Figure 11. Interim Product Monitor Process

The output of this monitor will enable to the team to track the overall completeness and quality of the output of the team. This is of course one of the key metrics to team health. If the team is creating high quality products, then that is an indication that they are performing well.

3.5 Risk Assessment and Management

The development of the node monitors is the key innovative development in this research program. As such it has development risks and potential payoffs. Our development process will include fallback positions to ensure that the monitors produce information that will be valuable to detecting and understanding team health issues even should some of the more ambitious technology developments prove infeasible.

The parts of the monitor with the highest development risks include the automated assessments of the communications, work products and deliverables. We are mitigating this risk by taking the following measures:

- Using text analysis tools and technologies that have reached a high degree of development maturity such as LSA and Information Extraction tools
- Using industry standard software integration and database integration methods to reduce integration risk
- Using other tools that are currently being used in other programs and projects such as EWALL and DCODE
- Where automated collection or analysis is planned, developing fallback positions that will minimize, but not necessarily eliminate team interaction with the monitor

As a result of this risk management strategy, EBR and NPS are confident that this effort will produce a workable set of cognitive monitors that can improve team transparency, reduce cognitive fragmentation, and alert to cognitive problems.

In addition, because we are basing our architecture on existing capabilities at EBR and NPS, there is no risk that we will fail to create a highly flexible and robust architecture able to support net-centric operations. Finally, because we are integrating available GOTS and COTS tools, there is no risk that the tools will not provide their intended support.

4. SUPPORTING TOOLS AND DOCUMENTS

4.1 Tool and Reference Documents

This chapter examines the tools and reference documentation that support the special functionality the human-focused architecture (Figure 12). The tools focus on three functions: 1) preventing cognitive fragmentation by supporting the activity awareness, task assessment, mutual understanding, and situation understanding cognitive enablers; 2) providing data to the cognitive monitors; and 3) helping follow-up on the problems that the monitors cue. The reference documents to be discussed here support the first two of these functions: countering cognitive fragmentation and providing data that the cognitive monitors need.

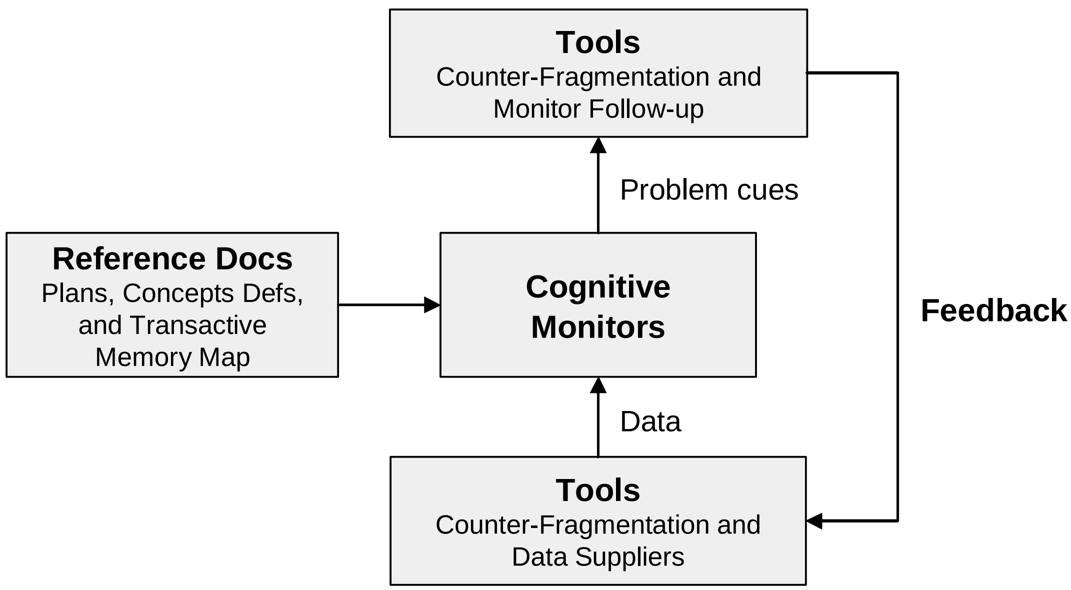

Figure 12. Roles of Tools and Plans in Human-Focused Architecture

This chapter has two main parts: the first discussing tools and the second discussing the reference documents. The tool discussion details the properties that tools should have to support the three functions stated above. It then describes a few of the specific tools selected for integration into the human-focused architecture. The reference document discussion reviews how these documents support the cognitive monitors.

4.2 Tools for the Human-Focused Architecture.

This section describes the capabilities that tools need in order to counter cognitive fragmentation, provide data to the cognitive monitors, or help team members solve the team problems cued by the monitors. There are numerous specific tools that can meet these requirements. Section 4.2.2 describes eight that EBR and NPS plan to integrate into the human-focused architecture.

4.2.1 Desired Tool Capabilities

Tool Capabilities that Counter Cognitive Fragmentation

Cognitive-fragmentation results from deficiencies in activity awareness, task assessment, mutual understanding, or situation understanding. Each of these knowledge enablers has several dimensions, each of which can be addressed by several different types of tools. Tables 7–10 describe some of the many tool capabilities which can reduce the risk of cognitive fragmentation.

Table 7. Tool Capabilities that Support Activity Awareness

Cognitive Category	Desired Tool Capabilities
1. Knowing what others are doing	• Provide team transparency, so that remotely located team members may "look over the shoulder" of people as they do their jobs. • Enable geographically dispersed people to review team member products as soon as they are produced, e.g., common data repositories • Post what team members are working on; e.g., task status boards.
2. Knowing how busy they are	• Show task status, so that people see whether others are getting behind in performing their tasks • Provide team transparency, to help people see what others are doing, and so see how busy they are
3. Knowing extent in accordance with plans and goals	• Depict the plan, showing the schedule for tasks and the people assigned to these tasks. Should include planned contingencies, and the circumstances under which these contingencies should be implemented • Describe task goals, and describe characteristic of products that support these goals.

Table 8. Tool Capabilities that Support Task Assessment

Cognitive Category	Desired Tool Capabilities
1. Tasks being worked on	• Post tasks team members are working on; e.g., task status boards (can show people working on no task) • Post tasks that need to be done with people who are working on (shows neglected tasks) • Couple transparency tools that help others know what people are doing with task descriptions that specify the work required to perform the task. • Couple product repositories that show what people are producing with descriptions of the products to be produced by each task
2. Progress	• Post work completed. • Provide access to repository of intermediate products, thus enabling review of products as parts are completed. • Enable communications announcing completion of task elements • Describe total work to be performed • Compare estimated time to completion with scheduled time • Couple estimates of task status and work accomplished with specifications of criteria for high quality product
3. Possible problems and impacts	• Couple written plan describing resources and information required to perform task with postings showing available resources and information • Compare estimated time to completion with scheduled time • Describe criteria for a good quality product, and specify information and resources required for the product • Couple above with postings showing available information and resources • Show dependency among tasks and goals
2. Resource needs	• Show plan describing information, equipment, tools, and people required to perform task • Couple plan depiction with listings of available and assigned information, equipment, tools, and people

Table 9. Tool Capabilities that Support Mutual Understanding

Cognitive Category	Desired Tool Capabilities
1. Others' expertise	• Summarize backgrounds and areas of expertise • Promote transparency so that all team members can observe capabilities as people work
2. Others' current understandings	• Allow or help people to explain and illustrate their views about the spatial, temporal, and organizational aspects of a situation. • Help people explain their positions: e.g., the views they advocate and the rationale for these views. • Help structure the dialog and environment for obtaining ideas • Help ensure that all voices are heard • Reduce possible perceived risks that people may have about sharing their views • Make available a means to review information available to others, to include access to the information feeds and data sources that others use
3. Extent others agree or disagree	• Couple means to know others backgrounds and expertise with means to perceive or infer their current understandings

Table 10. Tool Capabilities that Support Situation Understanding

Cognitive Category	Desired Tool Capabilities
1. Surface Understanding	• Show location and identity of objects along with contextual factors relevant to situation-based decisions • Show events on timeline • Show relationships among situation entities, to include what elements belong to the same organization and the nature of the relationships among these elements • Summarize changes to above • Show changes to above over time
2. Situation Model	• Show relationships among situation entities, to enable viewers to know how various entities impact one another • Show default values for a situation with uncertainties, when observed values not available • Project to future possible states that could evolve from a current situation, and state conditions under which these states would be most likely to arise • List the observables that indicate whether a particular situation interpretation (selection of situation model) is correct or not and can indicate which possible future states are coming to pass
3. Evidence Understanding	
Evidence audit trail	• Show the evidence used to generate the values of entities and events shown on the situation pictures • Highlight or list the factors responsible for the choice of situation model • Show estimated reliability for the evidence, and reasons for this reliability estimate
4. Uncertainty Understanding	• Convey uncertainty about the elements in the spatial, temporal, and organizational views • Show uncertainty about the situation relationships and default values for situation elements • Show uncertainty about the evidence supporting situation inferences • Show uncertainty about the "type" of situation being encountered

Tool capabilities that support monitor data input needs

The cognitive monitors indicate levels of workload, task status and progress, cognitive flow, and product quality. These monitors are designed to generate their estimates autonomously, using data that already resides within the team that they can tap. Table 11 shows some characteristics of the data that each of the monitors need.

Table 11. Monitor Data Requirements

Monitor	Desired Data to be Provided
Coping	• Shows extent keeping up with schedule • Shows performance of non-essential tasks • Shows failure to perform some scheduled tasks • Comments: "I'm too busy to talk to you now"
Task Assessment	• Shows tasks complete, being worked on, progress, comparison with plan • Comments such as "I'll never finish this work on time"
Concept Flow	• Implies kinds of issues being addressed • Implies inflowing and outgoing, and to whom • Shows issues communications address • Shows issues being deposited into databases • Shows match between people who contribute to concepts and expertise on the team • Shows match between issues being addressed and what should be addressed
Intermediate Products	• Shows types of products being deposited into databases or transmitted to others • Shows issues that have been addressed in these products • Enables comparison of issues addressed with specification of issues that should be addressed

In order to support the data needs of the monitors, tools need to generate these data. There are four types of tools that are able to do this: task aids, program management tools, databases, and communications.

Task aids are tools that help team members collect, organize, and manage information. The task aids that best support the monitors are those that can provide data about the kind of information a person is working on and how that person is evaluating or using the information.

Program management tools can track tasks and estimate variance between actual and planned progress. The ones needed here can provide data for tracking and evaluating progress.

Structured databases (including structured web sites) label the data they contain. For example, a database on company employees might specify an employee's name, position, salary, and supervisor. In a database, each of these items is paired with a role. Thus a person's salary, the number $42,000 would be paired with the label "salary." Because of this data labeling, it is possible to determine what kinds of data a team member is working with when he/she accesses the database. Databases that allow monitoring of the data fields being accessed are useful both for inferring concepts being addressed and identifying intermediate products being worked on and deposited.

Electronic Communications such as e-mail, and chat can potentially be captured as free text flows. Voice communications can also be captured and converted into free text. The content of unstructured databases are unlabeled text. When analyzed using content analysis tools such as latent semantic analysis or information extraction, these texts can convey the concepts team members are addressing or talking about. These analyzed texts can potentially support any of the monitors. For example, an e-mail stating that "I'm too busy to meet with you today" when analyzed is useful for inferring a team member's level of busyness. The information accessed from unstructured databases can also provide this information.

Properties of tools that help teams follow up on monitor-cued problems

The cognitive monitors cue general problems: difficulty accomplishing all the work that needs to be done, not keeping to the task schedule, failing to address key issues or not drawing on the team's expertise, and not creating some needed intermediate products. When the monitor cues any of these general problems, the team may wish to follow up in order to determine more precisely the nature of the problem and to identify possible remedies. The monitor follow-up tools help them do this.

Tools useful for monitor follow-up can help the team diagnose the issues and identify solutions in one of four different ways. They can provide diagnostic tests to pinpoint the problem, can suggest remedies, can help structure discussions, and can help team members examine and critique their understanding of the situation.

4.2.2 Overview of Selected Tools' Contributions

There are numerous tools available that help counter cognitive fragmentation, could provide data to the cognitive monitors, and can help teams follow up monitor cues of team problems. This section describes eight specific tools that we intend to integrate into our human-focused system. For completeness we also discuss communication tools as a generic class, which we of course also expect to include in the system. All of these tools can help teams avoid cognitive fragmentation. Four of the specific tools seem especially well suited for providing data to the cognitive monitors, and four can excel at helping teams follow-up on monitor cues to problems. Communication tools both help feed the monitors and enable team embers to discuss problems.

The eight specific tools are available commercially at COTS or from the government as GOTS. The first four are the war room's database exploration tools, DCODE for organizing summaries of documents, EWALL for organizing, managing and sharing information, and the COBRA earned value management system. The second four are the tools selected especially to support follow-on discussions that address potential problems cued by the monitors.

Table 12 summarizes how each of the selected tools can help reduce cognitive fragmentation. Tables 13 and 14 then summarize how the tools either input data that the monitors need or help teams follow-up on the monitor output.

Table 12. How Selected Support Cognitive Enablers that Reduce Fragmentation

	Tools that Provide Data To Monitors				**Tools that Help Follow-Up Monitors**				**Both**
	DB Explr	DCODE	EWALL	COBRA-EVM	Callab Advz	Mind Mgr	IBIS	VL	Comms
Activity Awareness									
What others are doing									
How busy they are									
Extent in accordance with plan and goals									
Task Assessment									
Tasks being worked on, and by whom									
Progress									
Possible problems and impact									
Resource needs									
Mutual Understanding									
Others' expertise									
Others' current understandings									
Extent others agree or disagree									
Situation Understanding									
Surface understanding									
Situation model									
Evidence									
Uncertainty									

Table 13. Summary of How Selected Tools Help Provide Data to the Monitors

	DB Explr	DCODE	EWALL	COBRA-EVM	Comms
Coping					
Extent keeping up with schedule					
Failure to perform some scheduled tasks					
Comments: "I'm too busy to talk to you now"					
Task Assessment					
Tasks complete, being worked on and by whom, and comparison with plan					
Comments such as "I'll never finish this work on time"					
Concept Flow					
Kinds of issues being addressed					
Issues inflowing and outgoing, and to whom					
Issues communications address					
Issues being deposited into the database					
Intermediate Products					
Types of products being deposited into database or transmitted to others					
Issues that have been addressed in these products					

Table 14. Summary of How Selected Tools Help Provide Data to the Monitors

	Collab Advzr	Mind Mgr	IBIS	VL	Comms
Diagnostic tests to pinpoint problem					
Suggest remedies					
Structure discussions					
Examine situation					

4.2.3 Discussion of Selected Tools

Tools that counter cognitive fragmentation and provide data to the monitors

1. **Database Exploration.** In this architecture, the system database is the central repository for all of the information being collected and all of the information being produced. It is the repository for all of the team's intermediate and final data products. Because the database is aligned with the system's formal ontology, every table and data field is unambiguously

associated with domain concepts. Team members use the database exploration tool to review, retrieve, and deposit database information.

Support to understandings:

a. Task assessment. Because every authorized team member can review the information in the database, other team members can infer what tasks are being worked on providing the task produces intermediate products deposited in the database and the team members know what information is associated with the product. Team members can infer task progress by noting the rate at which the information is deposited. They can infer problems if the rate of deposit is too slow. In addition, they can infer if progress is being impeded by information unavailability if they know that information that a task needs to retrieve from the database is not there.

b. Mutual understanding. By reviewing the information that other team members produce, team members can infer what concepts these team members are addressing and can judge the extent to which they agree or disagree with these concepts. If the team members have sufficient background in an area, they can judge the level of expertise of the team members producing the information.

c. Situation Understanding. As the repository for information and products, the database contains information about the current situation and the evidence supporting that information. By reviewing the database contents, team members can update their understanding of the situation and evidence, and can judge the extent to which the information is incomplete or imprecise.

Data Provided to Monitors. The database transaction records reference the information that team members deposit, review, and extract from the database. These data illuminate how well team members are keeping up with schedule, what tasks are being worked on and by whom, what tasks are compete, what issues are being deposited into the database, and the state of intermediate product.

2. **DCODE** (Decision Making Constructs in a Distributed Environment**)**. DCODE seeks to "improve the ability of distributed group decision makers to evaluate, share, and integrate decision-relevant information items," and "to reduce the time and effort devoted to conflict resolution and consensus building in reaching an overall group decision" (DCODE brief). DCODE works by encapsulating critical meta-data about an information item in easily shared Information Objects (IOBs). Each IOB labels an information item with a unique identifier, specifies the issue it addresses, and notes the team member who created it. The IOB also incorporates critical meta-data on the information item's credibility, timeliness, effect (extent it supports or undermines a position) and importance (weight it should be given). IOBs help teams consider the full range of information available on a topic and helps them to balance the diversity of viewpoints expressed in this information, taking into account the credibility of the information source. DCODE maintains an audit trail between an IOB and the information it references, enabling all team members to easily review the original source information. DCODE's ability to capture source meta-data is important part of the Human-Focused architecture. SPAWAR developed DCODE as part of ONR's Human System's Department.

Support to understandings:

a. Activity awareness (what others are doing). Because each IOB references the name of the person who created it, team members can determine what information others on the team are reviewing, and so infer the issues that they are working on.

b. Mutual understanding (other's current understandings). Each IOB summarizes its creator's evaluation of the information item, including that creator's views on the source's credibility, on the item's impact on an issue to be evaluated, and on the importance of the issue. The set of IOBs created by a team member reflects that team member's understandings on team issues. By reviewing the information item that the IOB summarizes, other team members can determine the extent to which their views about the information align with the views of the IOB's creator.

c. Situation understanding (evidence). The IOBs summarize the evidence for and against a team position as needed to understand the diversity of viewpoints on an issue. IOBs as a set incorporate three drivers in evaluating a position from the information about that position: the number of information items with a particular position, the strength of the information source's arguments (importance in the IOB), and the credibility of each source.

Data Provided to Monitors. DCODE records team members' capsule summaries of documents. These records therefore can convey the issues a team member has been addressing, and can provide these summaries to the monitors.

3. **EWALL** helps distributed team members "collect, organize and view graphical and contextual information, to comfortably collaborate in large, distributed and decentralized teams, as well as to maintain their individual ways of working (MIT brochure). EWALL can extract information from diverse sources, structure the information in a standard card format, and send the information to team members that need it. Team members can integrate each card in their input stream into their personal viewing space. When they do so, EWALL infers the team member's interests in the information and also infers how the newly integrated information relates to other information that that team member is working with. Based on its inferences, EWALL can automatically route information to team members who need it, whether the information is retrieved from sources outside of the team or produced within the team. Because each team member can view other member's card layouts, EWALL strongly supports team transparency, helping each team member know what other team members are working on. EWALL is sponsored by ONR's Human System's Department.

Support to understandings. Because of its ability to increase team transparency, EWALL can help unify team members' understandings in many areas. Areas where it provides the most direct support are:

a. Activity awareness (what others are doing). EWALL allows each team member to view other member's EWALL work space. Thus, it enables each team member to directly see what other team members are working on. Because EWALL can deposit team member's information products into a common team-viewable data repository, it helps team members infer what people are working on by reviewing what others have produced.

b. Task assessment (tasks being worked on and progress). EWALL supports this indirectly, as a by-product of team transparency. If team members know the work required to support team tasks, then team members can infer what tasks are being worked on by knowing what each team member is doing. If team members know the steps required to complete a task, then reviewing the work enables people to infer task progress. Note that EWALL by itself is not sufficient for task assessment. This assessment requires knowing not only what people are working on, but also knowing what work is required for each task.

c. Mutual understanding (others current understandings). Like task assessment, support to mutual understanding is another by-product of team transparency. By reviewing how a team member is interpreting received information, other team members can infer the extent to which this interpretation aligns with their own. By reviewing what another team member is doing, other team member's can sometimes infer the extent to which that team member's views on team goals and plans align with their own. In addition, by routing team member's work products to other team members, EWALL helps team members review these products and thus helps them determine the extent to which the views on the forwarded cards align with their own views

Data Provided to Monitors. EWALL encapsulates information onto a set of cards, records the source of the information, and routes the information to team members that might use it. It also records who is interested in the information and how they are relating new information to older material. Therefore EWALL can record the concepts that a team member receives, the source of these concepts, the concepts the team member is working on, the concepts that the team member is producing, and the destination of concepts produced. EWALL is a powerful source of information to the concept flow monitor.

4. **COBRA EVM** provides information on actual task and plan status. To use the tool, the team enters plan estimates for schedule and labor for each milestone, each task and for all performance measures. In addition, the planner specifies the "earned value" accrued when each milestone is achieved. At various time intervals, team members enter actual data for labor and milestone achievement. The system then calculates the earned value of the work performed given the milestones achieved and reports cost and schedule variances. Cost Variance (CV) is the difference between the planned and actual resource usage for an element of work. A negative variance means that more money was spent for the work accomplished than was planned. Schedule Variance (SV) is the difference between the budgeted cost of work performed and the earned value for an element of work. Any difference is called the Schedule Variance. The tool will provide graphs of the overall program or individual tasks that may be underperforming. Cobra will also calculate the Cost Performance Index (CPI) and the Schedule Performance Index (SPI). Using these indexes, team members can calculate final cost (budgeted cost /CPI) and final project duration (planned project duration/time based SPI). The purpose of earned value management is to integrate budget and performance measures to determine actual project status.

Support to understandings. EVM collects data on task performance to support project tracking for reporting to management and clients. It provides excellent support to activity awareness and task assessment, but only with the granularity needed for project support.

a. Activity awareness. By tracking task progress, EVM can help team members be aware of what team members are doing, how well they are keeping up with schedule, and the extent to which the task is proceeding in accordance with the plan.

b. Task assessment. This is the purpose of EVM. It provides visibility into the tasks being worked on, progress, possible problems, and resource needs. Note because it does not do this continuously on an hour by hour basis, it should be supplemented by other methods that do provide more continuous monitoring.

Data Provided to Monitors. Team members manually enter task progress and the plan into EVM, which then computes the variance of progress with the plan. EVM can provide these performance data to the cognitive monitors to support the coping and task assessment.

Tools that counter cognitive fragmentation and provide data to the monitors

5. The **Collaboration Advizor** helps teams diagnose and fix cognitive problems. To use the tool, each team member answers a short questionnaire about the collaboration environment, team behaviors, task accomplishments and team member understandings. Each of these questions is diagnostic of team problems in one or more of twelve "cognitive enablers"—areas of understanding that are important for team members to work together effectively. The tool then assembles the individual responses to create a "team view." This view summarizes team strengths and weaknesses for each of the twelve knowledge areas, and can recommend actions that address team weaknesses. By showing how team members (anonymously) responded to each of the questions the Collaboration Advizor team view can reveal where team members agree and disagree about their understandings of team issues. In addition, the Advizor can track team changes over time, so that members can see whether actions that they have taken to address problems are working, or whether the team needs to try alternative actions. Evidence Based Research developed the Collaboration Advizor as work sponsored by ONR's Human System's Department.

Support to understandings:

a. Activity awareness (accordance with plan and goals). The Collaboration Advizor asks many questions intended to reveal the extent that team members understand team goals and plans. It can help make team members aware of the risk that some team members may fail to act in accordance with team plans and goals.

b. Task assessment (possible problems and impact). The Advizor probes for problems that team members may have in carrying out their tasks and in supporting each other. For example, it asks about whether team members have the experience and background to carry out their tasks, and whether they understand task dependencies as needed to adjust their tasks should other tasks be having problems.

c. Mutual understanding (extent others agree or disagree). Support to mutual understanding is one of the Advizor's principal objectives. The Advizor's team view displays the number of people agreeing or disagreeing with each of the questions asked, enabling all team members to see the degree of agreement and disagreement on numerous issues. For example, the team view might show that five of eight team members agree with the statement "There are no specified criteria for mission success." In such cases, those members who believe that there are such criteria should explain them to the others.

Support to Monitor Follow-up. The Collaboration Advizor is a premier tool for following up monitor cues. It can help team pinpoint the underlying cognitive problems responsible for the monitors' output readings, and it can suggest remedies. Furthermore, by creating a set of forms that encapsulate team issues and illuminate team member differences, the Advizor can help structure the follow-up discussions.

6. **Mind Manager**. This tool helps teams organize their ideas in a brainstorming environment. Mind Manager organizes ideas hierarchically, showing the relationship of elaborations or detail thinking on an issue. It displays this organization in a flexible way that encourages discussion.

Support to understandings:

a. Mutual understanding. Mind Manager's ability to help structure and depict ideas helps all team members be aware of what other's views are and helps them discuss areas of agreement and disagreement.

Support to Monitor Follow-up. Mind Manager's ability to help structure discussions helps teams explore team issues and identify remedies. For example, team members can describe specific behaviors that substantiate or refute the significance of the issues raised by the monitors. If the behaviors are substantiated, the team might discuss the root cause of the behaviors and then brainstorm on methods for addressing the problem.

7. **IBIS (**Issue-Based Information System). IBIS is a systematic method for developing consensus on solutions to "wicked" problems, drawing on the work of Kuntz and Rittel in the 1970s (Kuntz & Rittel, 1972). Wicked problems are problems in which the nature of the problem is not clear at first, but can emerge as the group discusses the pro's and con's of various proposed problem solutions. There are several different tools that support the IBIS process (e.g., gIBIS, Compendium), one of which would be selected to implement the architecture. Each of these tools helps the group structure its dialog into a set of Questions, Ideas, and Arguments. The question states the problem as a question to be answered. The ideas are possible answers to the question, and the arguments are the reasons for supporting or objecting to an idea (http://www.touchstone.com/tr/wp/IBIS.html). Generally, the IBIS process helps teams explore the nature of the problem, encouraging a full diversity of viewpoints, as in brainstorming. The process then also helps the teams consolidate these viewpoints as required to support development of consensus.

Support to understandings. An IBIS tool helps team members be aware of each other's viewpoints and the reasons for these viewpoints.

a. Mutual understanding (others current understandings). In an IBIS-structured dialog, team members share their current interpretations of possibly poorly defined team goals, state their ideas on how to achieve these goals, and articulate their views on the strengths and weaknesses of proposed solutions. By making these views explicit, IBIS helps team members know what each other's views are, and equally important, helps team members know each other's reasons for their views.

b. Mutual understanding (Extent others agree of disagree). By making explicit different viewpoints on an issue, IBIS can also clarify where people agree or disagree, and if they disagree, can help clarify why.

Support to Monitor Follow-up. IBIS helps structure team discussions. When team members are debating the nature of the team's problems, IBIS can help collect and compare team member views on what the source of the problem is, the different ways that the team can address the problem, and the strengths and weaknesses of each of these different ways.

8. Visual Links. Visual Links is an application that helps people understand the content of the database and explore the relationships among the data.

Support to understandings:

a. Situation understanding. When the database stores information about the situation, Visual Links can support all facets of situation understanding. It supports surface understanding by help people review the facts about the situation—the nature of the situation entities and situation events. It support understanding how these entities impact each other by revealing relationships in the situation, thereby helping people make forecasts and predictions. It helps people understand the evidence by linking conclusions to supporting and contradicting observations. It helps people understand uncertainties by clarifying gaps and imprecision in the situation information.

Support to Monitor Follow-up. When team problems stem from conflicting incomplete concepts about the situation, Visual Links can help team members examine what is known about the situation. When team problems manifest themselves as incomplete or poor quality intermediate products, Visual Links can help the team analyze their product to determine areas that require improvement.

General Communication Tools

Communication tools include the telephone, e-mail, chat, video-teleconferencing, broadcasts, web-posting and other ways for people to convey information to each other. We include them in this discussion because they contribute to numerous aspects of teamwork.

Communication tools are pervasive now, and will be part of any distributed collaboration architecture. We include them for completeness, because they are important for preventing cognitive fragmentation, for feeding the cognitive monitors, and for enabling teams to address team problems.

From the perspective of cognitive fragmentation, communication tools may be classified by their ability to provide feedback for understanding what's being said. In normal conversation, speech occurs in segments. After a speaker finishes a thought, the information recipient signals the extent to which the thought is understood. The speaker upon receiving the signal either continues if the signal indicated understanding, or rephrases or elaborates if the signal indicated an undesired level of understanding. Occasionally the receiver will ask for clarification. Usually however the understanding of a thought it expressed through body language, facial expressions, tone of voice, or short informal words or phrases.

Because of the importance of these understanding cues, the ability of the medium to transmit these cues impacts the ease with which meaning can be transferred. The medium most effective for transfer of meaning is face-to-face conversation, since it can transfer all of these cues. Second are mediums that can convey body language, such as VTC. Third are voice communications, because they convey tone of voice. Next are text transmissions with immediate feedback. After that is text transmission without immediate feedback but in which feedback is very easy, such as e-mail. Last are medium in which feedback is not facilitated (and sometimes not possible) such as broadcasts or web pages.

In addition to facilitating understanding feedback, communication tools vary in their ability to convey relationships within a concept. For this use, medium that can present pictures are helpful. Face to face with white board is most effective, for it permits diagrams as well as providing immediate understanding feedback. For distributed teams, shared applications that enable diagrams with immediate feedback can be very helpful.

In our human-centric architecture, communication tools provide data to the cognitive monitors. Text can be directly input into the content analysis tools, and voice can be input after being transcribed into text. The content analysis tools, such as Latent Semantic Analysis or Information Extraction, can infer from this input the concepts being communicated and their source, and can often infer the destination of the concepts.

4.3 Reference Documents

This section addresses three reference documents that the cognitive monitors need. It describes each of these documents and summarizes its contribution to the cognitive monitors.

The three documents are the team's plan, a plan supplement that enumerates issues that the plan should address, and the team's expertise map. One of these documents, the team's plan, should be a part of nearly every team's arsenal. The others, the issues to be addressed and the expertise map, will also be valuable to most teams.

The plan specifies the team goals and describes a set of tasks for achieving these goals. It describes the goals in a manner intended to help team members understand commander's intent. Often, it will describe the desired end state.

In addition to specifying the goals and tasks, plans specify resources, schedules with milestones, dependencies, contingencies, and performance measures. Generally, a plan specifies who is responsible for carrying out the task, and the information required and the equipment and materials allocated. The plan specifies when the tasks are to be done and what should be accomplished at specified times (the milestones). Plans state the other tasks and goals that depend on the task. Because plans often cannot ensure success under every possible circumstance, the plan specifies those circumstances under which it may not work and defines the alternative actions to be carried out under various other circumstances (the contingencies). Finally a plan may specify performance measures for measuring progress as the plan proceeds.

In the human-centric architecture, the plan is formally documented in the Earned Value Management application. This system can export it to the monitors.

The plan documentation is required to support the coping monitor and the evaluative parts of the task assessment monitor. Because the plan communicates to the monitors when tasks should be accomplished, if the monitor knows when tasks are being completed, it can then determine whether people are falling behind (coping meter input), can determine plan progress with respect to schedule, and can determine scheduled tasks that are not being addressed.

Issue enumeration supplement. In our description of the concept flow monitor, we distinguished between the plan and the list of issues to be addressed in carrying out the plan. The plan itself enumerates a series of steps to take to achieve a goal. In contrast, the issue enumeration lists issues that should be addressed when carrying out the plan. In the case of disaster relief, the issues might include determine the populations' needs at various locations, determining the urgency of these needs, determining needed medical supplies, and determining how to transport the supplies to the people who need them. The plan issue supplement enumerates the issues that need to be addressed.

This supplement is important to the concept flow monitor. It defines the concepts that the plan specifies should be addressed, provides the materials that LSA needs to learn to recognize these concepts, and provides the reference that enables the concept flow monitor to judge whether the team is addressing the concepts it needs to.

Team expertise map. This map specifies the issues that team members are expert at or are responsible for handling. It enables the concept flow monitor to note the extent that team members are drawing on team expertise when they address an issue.

5. ARCHITECTURE

The architecture provides the connectivity and information management needed to support net-centric operations. This peer-to-peer agent-based architecture facilitates information flow, helps integrate a collaboration tool suite tailored to team needs, and gathers and manages the cognitive node monitors. Its use of the Groove peer-to-peer application provides for robust connectivity, supporting even team members at nodes behind firewalls, with low bandwidth access, or having interrupted access. Its use of COABS for agent management facilitates use of intelligent that help manage information flow and integrate applications.

Development of this architecture is extremely low risk. Most of the architecture is currently operational at the NPS Gigalab and EBR war room. Additional upgrades will link the NPS and EBR systems and integrate agents for managing the data flows that the cognitive node monitors need.

The architecture is layered and geographically distributed. Every peer-to-peer collaborative node operates on the top of tactical wireless mesh network, such as one the described on Figure 13, which is integrated globally with the EBR War Room environment via the satellite or high-speed wired communications within the Global Information Grid (GIG) services in a way similar to Figure 14.

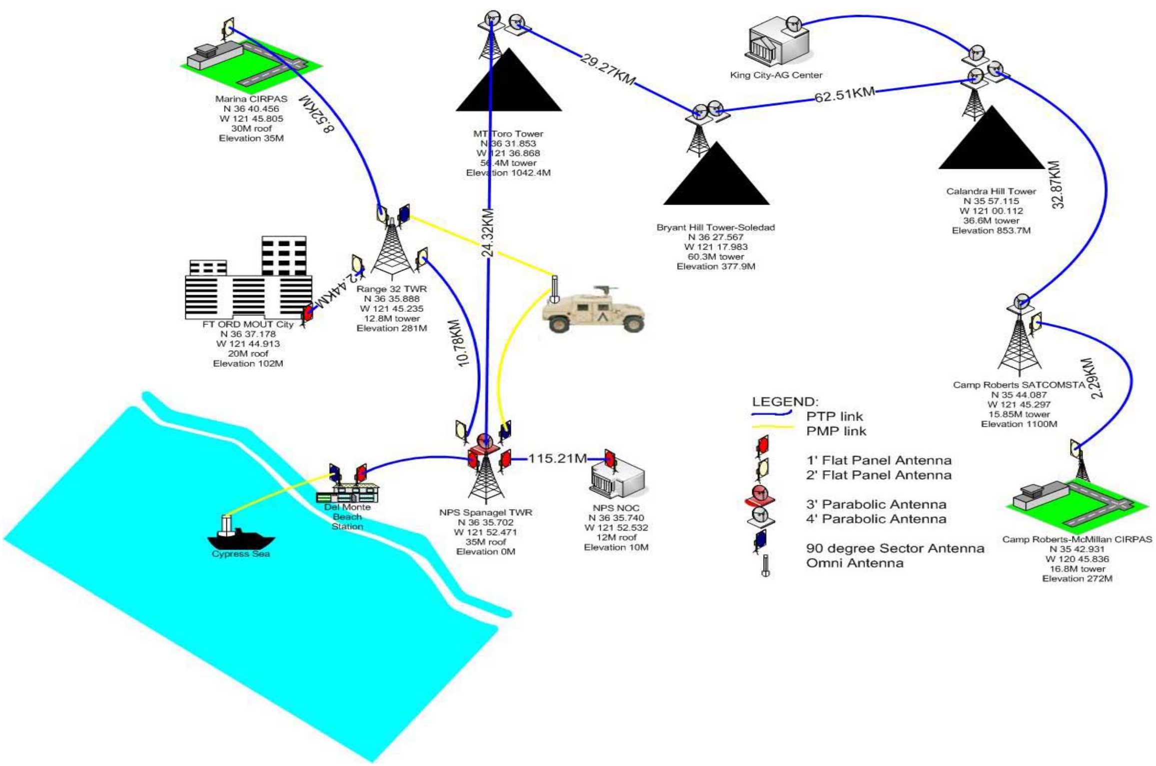

Figure 13. NPS Tactical Wireless Testbed for Sensor-Decision Maker-Tactical Operation Centers Collaboration Studies

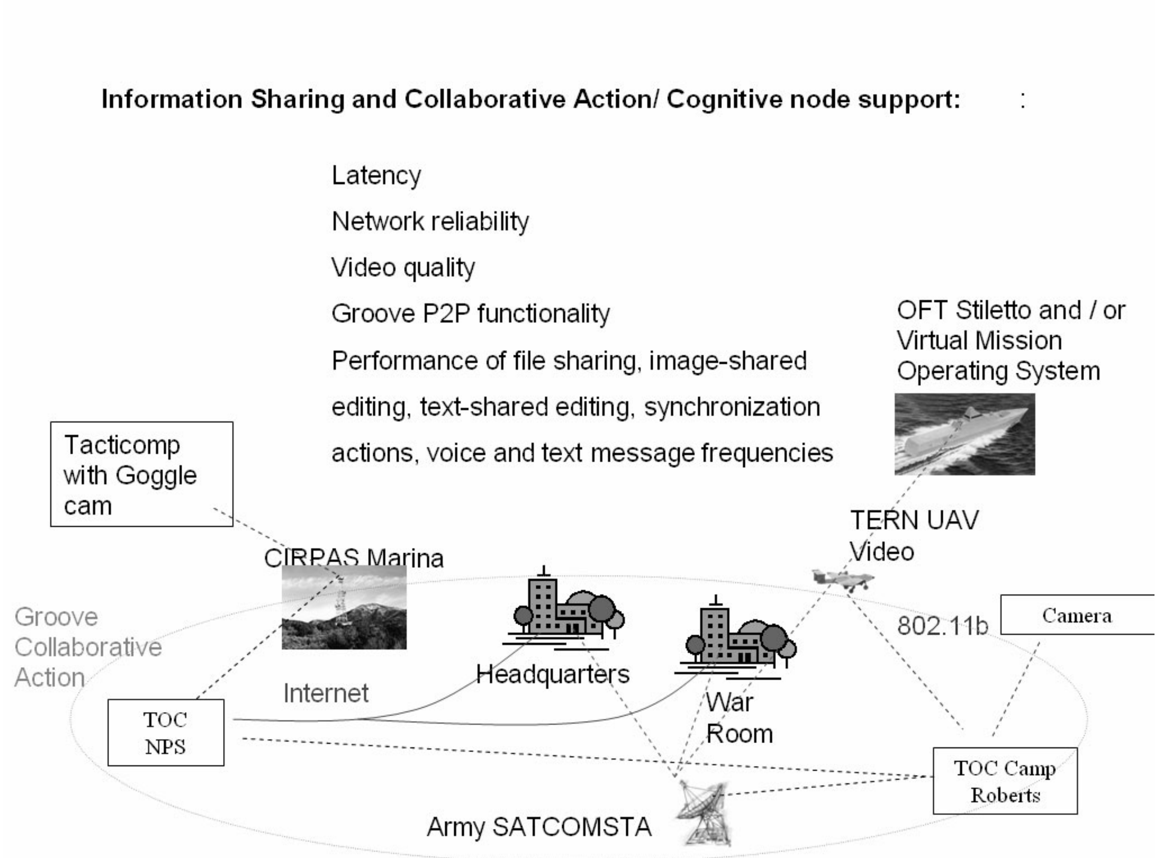

Figure 14. Network Level Integration of EBR War Room with NPS tactical Collaboration Testbed

Such infrastructure enables cognitive node connectivity at layers 1-7 in accordance with OSI communication stack model. The Groove clients reside at layer 7 of OSI communication stack at every sensor-decision maker grid node. They correspondingly enable peer-to-peer collaborative application flow across the grid encapsulating shared and situational awareness views (Figure 15)

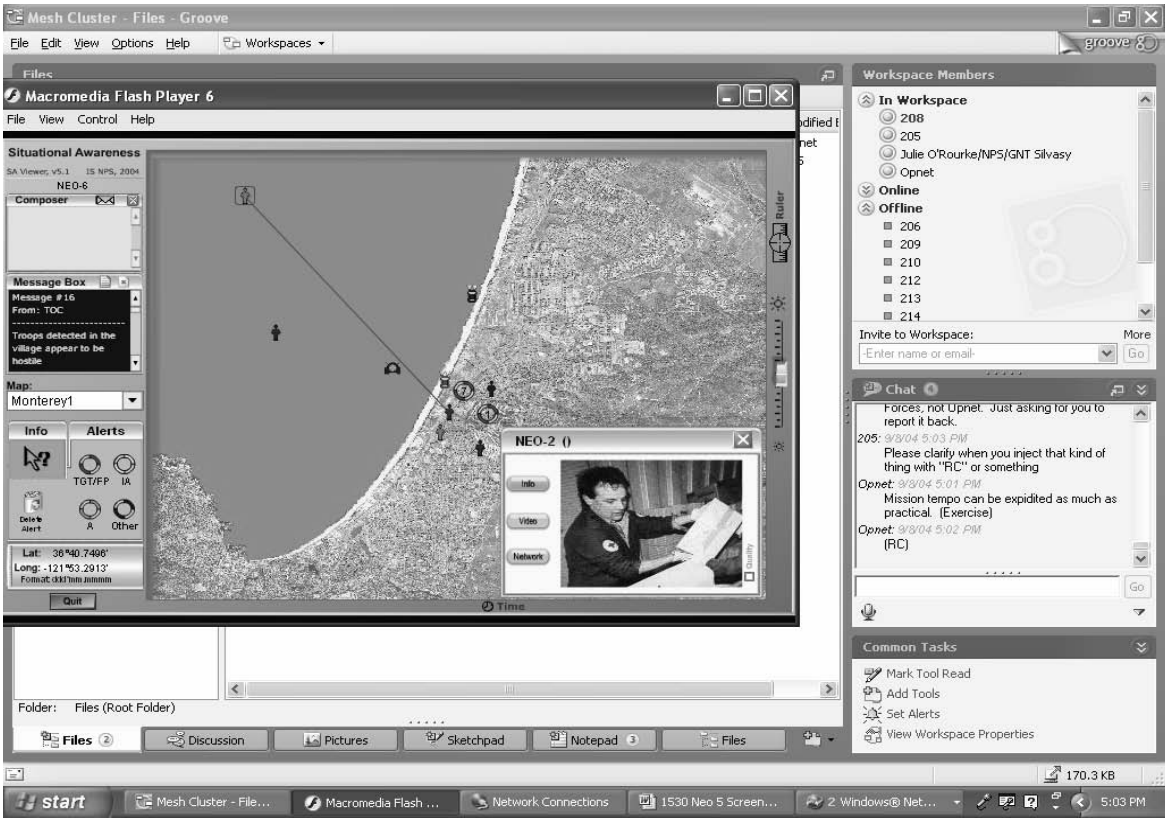

Figure 15. Situational Awareness View Shared by Multiple DMs and Integrated with Groove Peer-to-Peer Collaborative Environment.

Middleware agent services to collaborative clients ensure seamless integration of different applications residing on the War Room server and across the tactical grid nodes. The multi-agent middleware belongs to the lower level of application layer hierarchy within the proposed architecture:

OSI Application Layer:

-Cognitive tier (the cognitive node monitors)

-Peer-to-Peer collaborative applications tier (Groove, EWall)

-Situational Awareness agents (NPS CoABS model)

OSI Networking Layers (1-6).

The agents allow any application on behalf of decision maker to register on the grid and also to establish sensor-decision maker interfaces with Groove and EWall in order to ensure collaborative process monitoring up to the cognitive level. Figure 16 illustrates an example of agent architecture for integrating reconnaissance and surveillance applications in the collaborative environment. The integration mechanism is based on the CoABS agent services model.

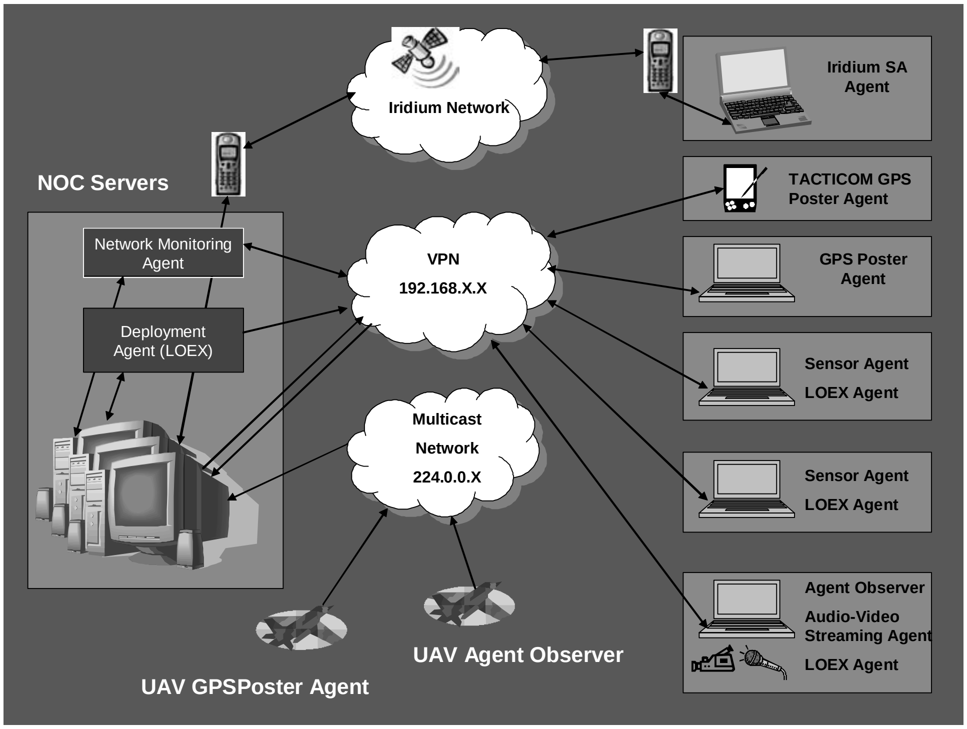

Figure 16. Multi-Agent Architecture for Application-Decision Maker Integration in Shared Collaborative Environment

By providing for ubiquitous application–decision maker integration the proposed multi-agent architecture allows unifying high level cognitive events monitoring (activity awareness, task assessment, mutual understanding, situational understanding) with lower level networking events awareness.

Figure 17 illustrates the model of lower (physical networking) level awareness brought up to shared collaborative environment via agents, which will be expanded in the proposed human-centric architecture to cognitive event “gauges”. Note that top level cognitive gauges in the upper left hand corner of Figure 17. These stop lights are the ones shown and explained in Figure 4 in Chapter 3.

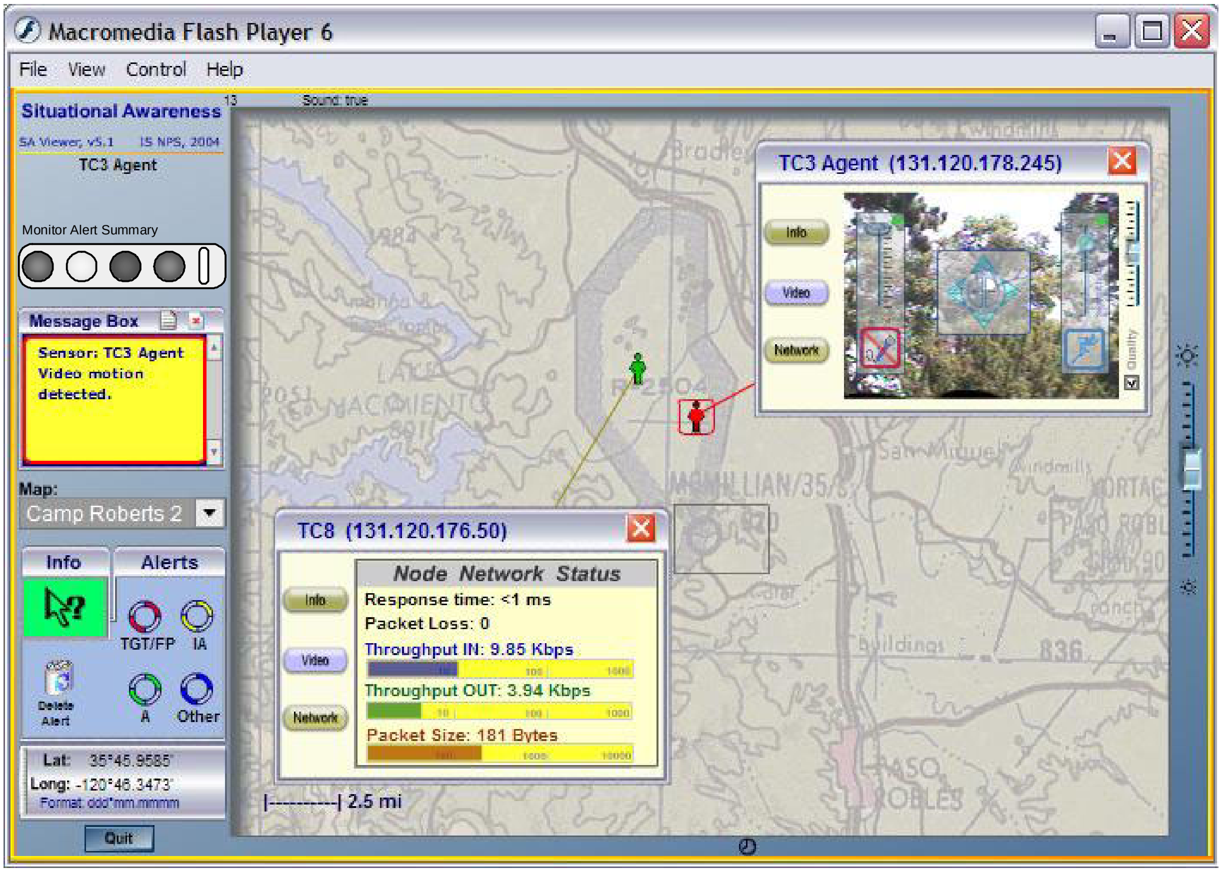

Figure 17. Lower Level, Physical Networking Events Monitoring via the Cognitive Node Agents.

In Figure 17 the levels of collaborative node monitoring include network (throughput, responsiveness, and packet loss gauges) and ISR applications (video option above). In the planned human-centric architecture the menu of info, video, and network monitoring options in the cognitive node agent frame will be expanded by the cognitive enablers described in the previous sections.

In figure 17 the alert window on the left is the agent response to the application event, namely video motion detection. In our proposed architecture for cognitive node monitoring similar events will be generated by the agent, but at the higher level of cognitive enablers, i.e. problems in task (task assessment), uncertainty (situation understanding), etc. This is indicated by the stop lights at the top of Figure 17.

Once the cognitive enabler alert is issued, the shared situational awareness view is captured and transferred to the EWALL for subsequent DECODE –based evaluation of importance, relevance, and other conclusions. It will be done in a way similar to the ISR application events association via the EWall as presented in Figure 18.

Figure 18. EWALL Integration with Application Event Awareness.

In figure 18 each row corresponds with agent-decision maker events, which are captured over time for an immediate or subsequent evaluation. The situational awareness view is the disclosure of one if the event cards. Once the cognitive enablers are added to agent monitoring levels, they will appear in the evaluation view accordingly.

6. BENEFITS TO NAVY

The new military doctrines of Network Centric Warfare and the Navy's ForceNet are transforming our military into a much more agile force, able to comprehend the situation and the commander's intent and quickly seize opportunities and thwart risks through a broad diversity of often multi-national operations. These doctrines, though still evolving, are now starting to be put into practice. Both Operation Enduring Freedom in Afghanistan and Operation Iraqi Freedom in Iraq incorporated many elements of Network-Centric Warfare.

The intellectual foundation of these agile and responsive forces is the ability to quickly create a cognitively cohesive team, where every team member understands how his work fits with the work that others are doing, understands others' responsibilities and areas of expertise, knows what others are doing and how it contributes to the team goals, is aware of what others' views, and knows where team members agree and disagree with each other.

It is not easy to quickly form and connect ad-hoc teams with the special mix of disciplines and backgrounds needed to handle rapidly evolving situations. It is even more difficult to ensure that the team's members can understand and leverage each others' perspectives to create high quality situation assessments and plans. The human-focused architecture and cognitive monitors that this STTR will provide will increase team transparency, helping all team members achieve the common understandings necessary for effective teamwork. The architecture and system will also measure team performance, as needed to cue team members to possible problems that the team should address.

The cognitive monitors can also instrument team performance measurement, enabling team performance data to be collected automatically and non-intrusively. This capability will enable the Navy to systematically improve team performance by knowing the tools, training, and organizations that best enhance teamwork.

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